

High Multiplicity FVTX Trigger for Run15

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Itaru Nakagawa
RIKEN
and
FVTX Group

Outline

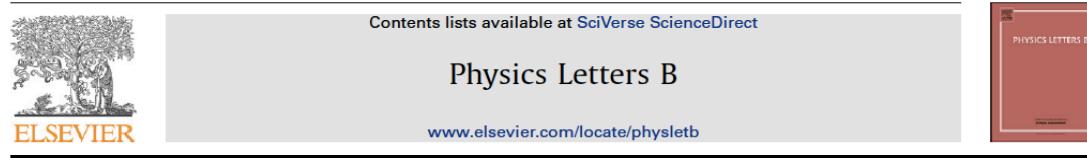
1. Physics
2. Statistical Goal (of high multiplicity events for pp)
3. Trigger Performance



MOTIVATION

CMS Reported “Ridge” feature in pp,pA

Physics Letters B 718 (2013) 795–814



Observation of long-range, near-side angular correlations in pPb collisions at the LHC[☆]

CMS Collaboration*

CERN, Switzerland

Submitted in October, 2012
(one month after data taking)

ARTICLE INFO

Article history:

Received 19 October 2012

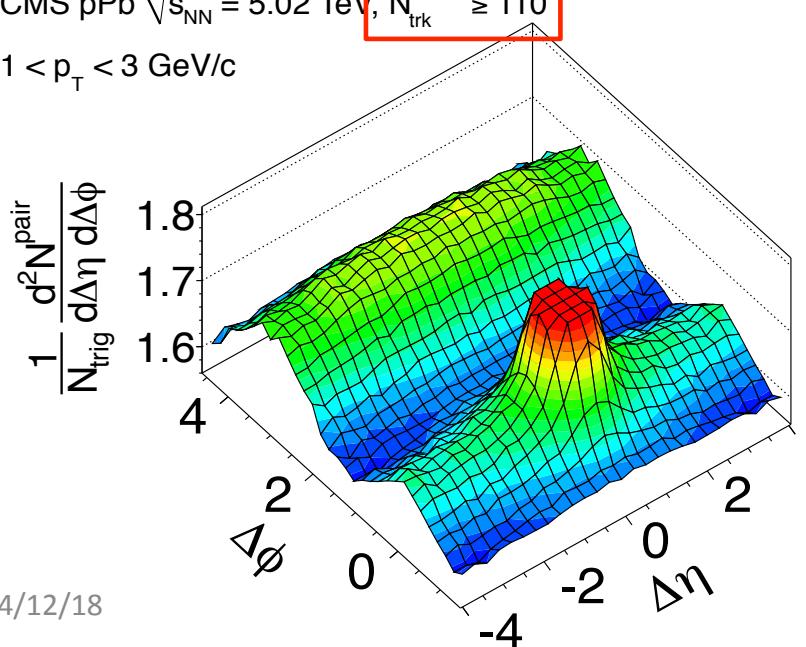
Received in revised form 7 November 2012

ABSTRACT

Results on two-particle angular correlations for charged particles emitted in pPb collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV are presented. The analysis uses two million collisions collected with the CMS detector at the LHC. The correlations are studied over a broad range of

CMS pPb $\sqrt{s_{NN}} = 5.02 \text{ TeV}$, $N_{\text{trk}}^{\text{offline}} \geq 110$

$1 < p_T < 3 \text{ GeV}/c$



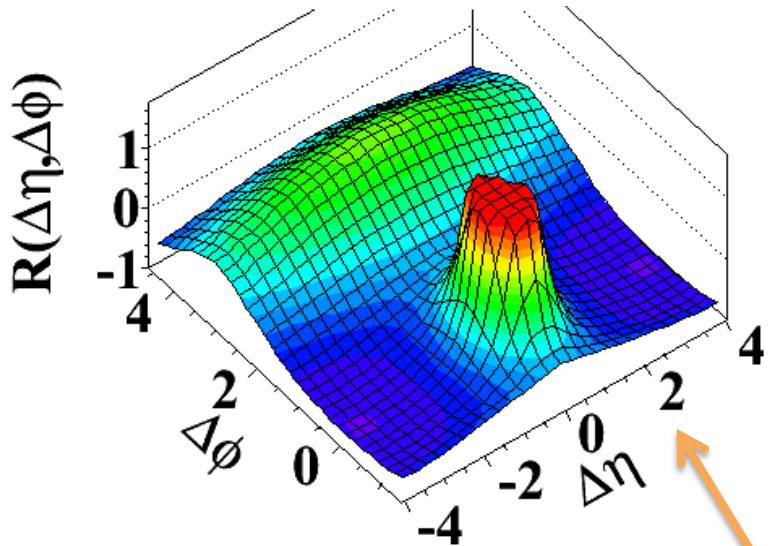
Yes, there is a ridge in pA!!!
Much more significant than in pp!

Confirmed later by ALICE and ATLAS

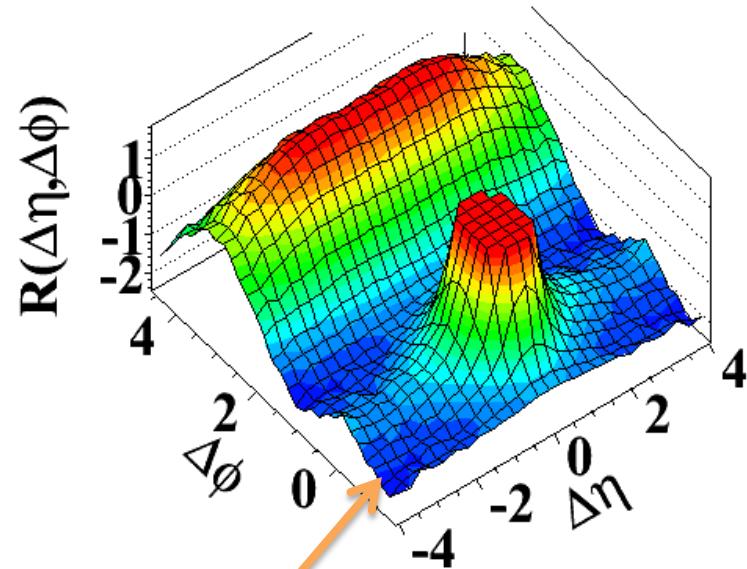
High Multiplicity Events is the key!

Two-particle $\Delta\eta$ - $\Delta\phi$ correlation

pp $\langle N \rangle \sim 15$, $1 < p_T < 3$ GeV/c



pp $N > 110$, $1 < p_T < 3$ GeV/c



$n_{ch} = 110$ in $\Delta\eta=4.8$

($dn_{ch}/d\eta \sim 23$)

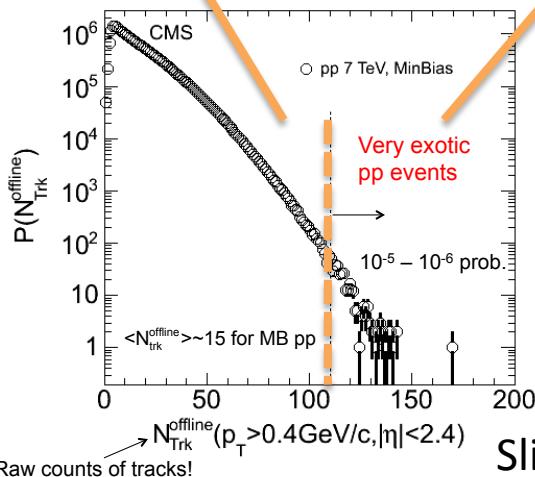
$\langle n_{ch} \rangle \sim 15$ for MB

$110/\langle n_{ch} \rangle \sim 7$

$10^{-5} \sim 10^{-6}$ probability

14/12/18

Very high-multiplicity pp events are rare in nature



Slide from Wei Lei, Rice University

pA vs. pp

Physics Letters B 718 (2013) 795–814



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Physics Letters B

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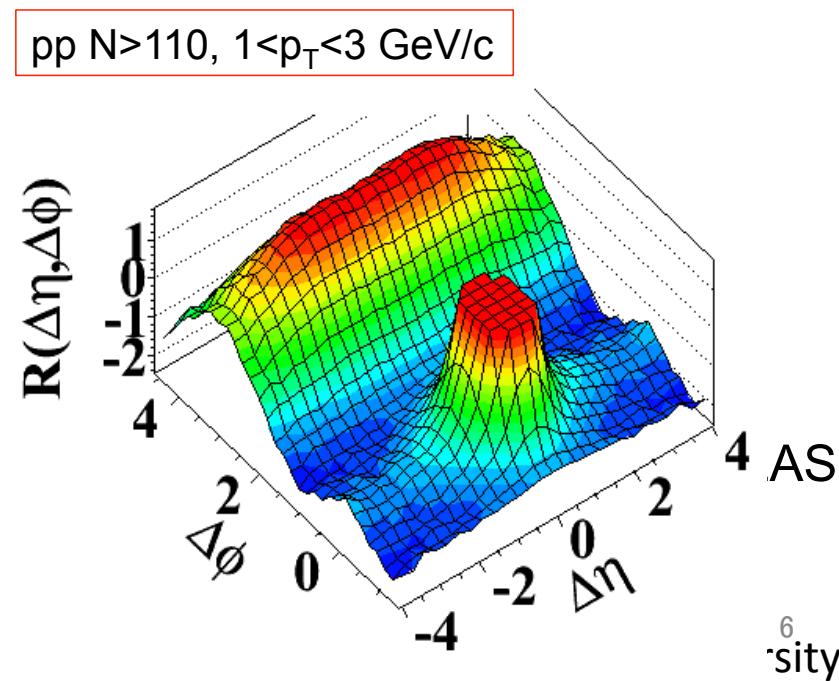
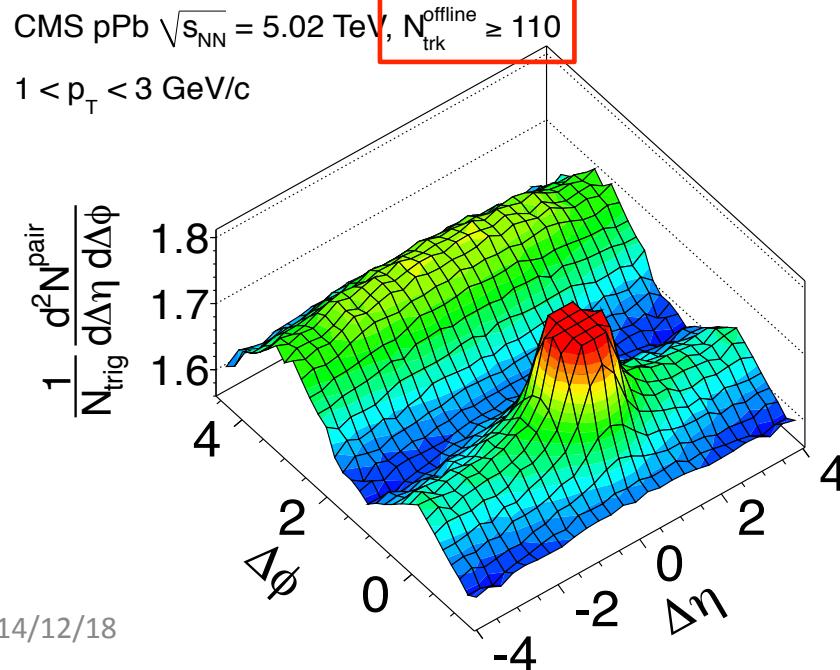
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ABSTRACT

Results on two-particle angular correlations for charged particles emitted in pPb collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV are presented. The analysis uses two million collisions collected with the CMS detector at the LHC. The correlations are studied over a broad range of

Signal is expected to be smaller in pp.
Requires more statistics than pA.



Collectivity in Small Colliding Systems

with High Multiplicity

RIKEN BNL Research Center Workshop

March 4-6, 2015 at Brookhaven National Laboratory



Experiment	pA, dA	pp
CMS	✓	✓
ALICE	✓	✓
ATLAS	✓	
PHENIX	✓	
STAR	?	

PHENIX History on Collective Motion in Small System

PPG152	Elliptic Shape at $\eta \sim 0$	d-Au	2013, March published	Anne Sicks
PPG161	Long-range ridge $y \sim 0$ + MPC	d-Au	Second submission	Shengli Huang
	v2, v3 High multiplicity trigger in BBC	3He-Au	2014, Dec Preliminary	Shengli Huang
	Long-range ridge $y \sim 0$ + FVTX + MPC?	p-p		

Observed v2 in dAu @ PHENIX

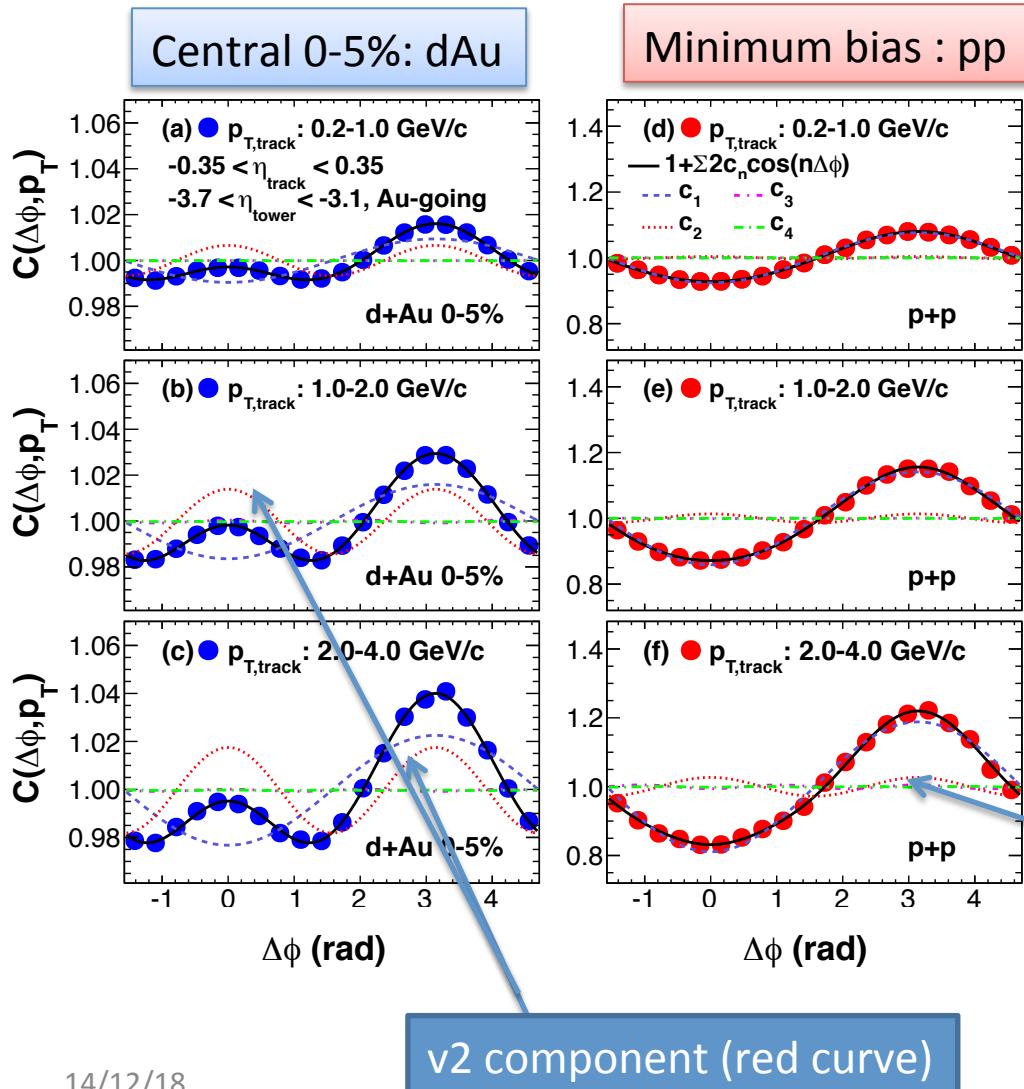
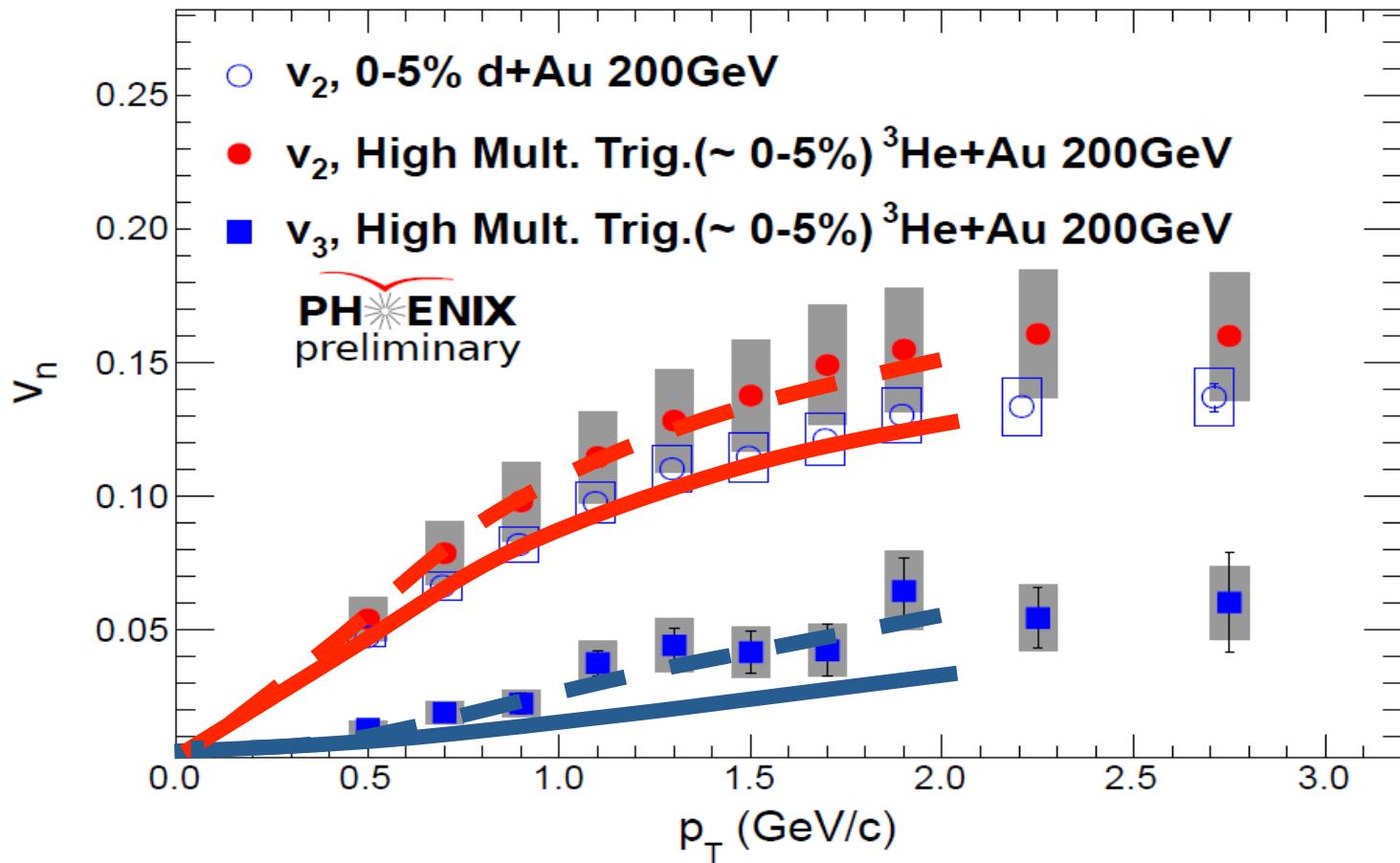


FIG. 1: The azimuthal correlation functions $C(\Delta\phi, p_T)$, as defined in Eq. 2, for track-tower pairs with different track p_T selections in 0%–5% central $d+Au$ collisions (left) and minimum bias $p+p$ collisions (right) at $\sqrt{s_{NN}} = 200 \text{ GeV}$. From top to bottom, the track p_T bins are 0.2–1.0 GeV/c , 1.0%–2.0 GeV/c and 2.0%–4.0 GeV/c . The pairs are formed between charged tracks measured in the PHENIX central arms at $|\eta| < 0.35$ and towers in the MPC-S calorimeter ($-3.7 < \eta < -3.1$, Au-going). A near-side peak is observed in the central $d+Au$ which is not seen in minimum bias $p+p$. Each correlation function is fit with a four-term Fourier cosine expansion; the individual components $n = 1$ to $n = 4$ are drawn on each panel, together with the fit function sum.

PPG161

Elementary process (not flow)

Very nice reception of ${}^3\text{He}+\text{Au}$ results at Initial Stages Conference
 First results shown in Shengli's talk!
<http://is2014.lbl.gov/>



Glauber IC + Hydro ($\eta/s=1/4\pi$) + Hadronic Cascade (PRL 2014)
 Dashed Lines – adding pre-flow (see Romatschke's talk)

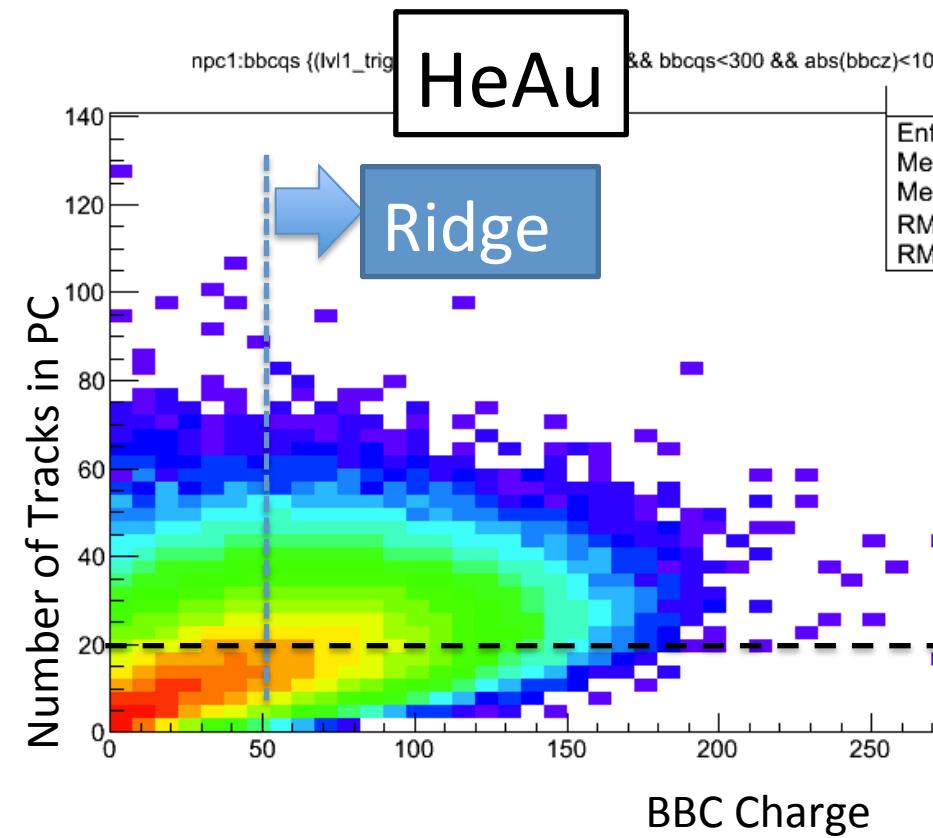
BBC High Multiplicity Trigger for HeAu

Run Summary

Note: L1 Trigger Scaler Entries in pink indicate an approximate count due to the fact that Run Control may have crashed and the run was not ended properly.
select * from trigger where runnumber = 415751 order by bitnb

Name	Bit Mask	Scale Down	State	Raw Trigger Count	Raw Trigger Rate	Live Trigger Count	Live Trigger Rate	Scaled Trigger Count	Scaled Trigger Rate	Livetime
Clock	0x00000001	500000	Enabled	49640794606	9383893.12	45945784411	8685403.48	91891	17.37	0.93
BBCLL1(>0 tubes) narrowvtx	0x00000002	10	Enabled	284171900	53718.70	263942420	49894.60	23994765	4535.87	0.93
BBCLL1(>0 tubes)_central48_narrowvtx	0x00000004	0	Enabled	11858738	2241.73	11016910	2082.59	11016910	2082.59	0.93
BBCLL1(>0 tubes)_central49_narrowvtx	0x00000008	0	Enabled	9444480	1785.35	8773510	1658.51	8773510	1658.51	0.93
BBCLL1(>0 tubes)_central50	0x00000010	9999999	Enabled	20630850	3899.97	19168559	3623.55	1	0.00	0.93
BBCLL1(>0 tubes)	0x00000020	581	Enabled	652894964	123420.60	606513494	114652.83	1042119	197.00	0.93
BBCLL1(>0 tubes) novertex	0x00000040	12500	Enabled	1287423193	243369.22	1197471408	226365.11	95790	18.11	0.93
BBCLL1(>0 tubes) narrowvertex CopyA	0x00000080	9999999	Enabled	284171902	53718.70	263942420	49894.60	26	0.00	0.93
BBCLL1(>0 tubes) narrowvertex CopyB	0x00000100	9999999	Enabled	284171902	53718.70	263942420	49894.60	26	0.00	0.93
ZDCNS	0x00000200	1000	Enabled	225143077	42560.13	209765833	39653.28	209556	39.61	0.93
ZDCLL1wide	0x00000400	1000	Enabled	227387409	42984.39	212686791	40205.44	212474	40.17	0.94
ZDCLL1narrow	0x00000800	227	Enabled	58366913	11033.44	54629599	10326.96	239604	45.29	0.94
ERTLL1_4x4a&BBCLL1	0x00001000	0	Enabled	280197	52.97	261305	49.40	261305	49.40	0.93
ERT_4x4b&BBCLL1	0x00002000	0	Enabled	99788	18.86	93122	17.60	93122	17.60	0.93
ERT_4x4c&BBCLL1	0x00004000	1	Enabled	839415	158.68	783099	148.03	391550	74.02	0.93
ERTLL1_Electron&BBCLL1narrow	0x00008000	0	Enabled	683708	129.25	637366	120.49	637366	120.49	0.93
ERT_2x2	0x00010000	9999999	Enabled	15324795	2896.94	14285404	2700.45	1	0.00	0.93
ERT_4x4b	0x00020000	0	Enabled	121832	23.03	113533	21.46	113533	21.46	0.93
MUIDLL1_N2D&BBCLL1	0x00040000	0	Enabled	395923	74.84	345631	65.34	345631	65.34	0.87
MUIDLL1_S2D&BBCLL1	0x00080000	1	Enabled	951362	179.84	858644	162.31	429322	81.16	0.90
MUIDLL1_N1D&BBCLL1	0x00100000	9999999	Enabled	3908139	738.78	3584329	677.57	0	0.00	0.92

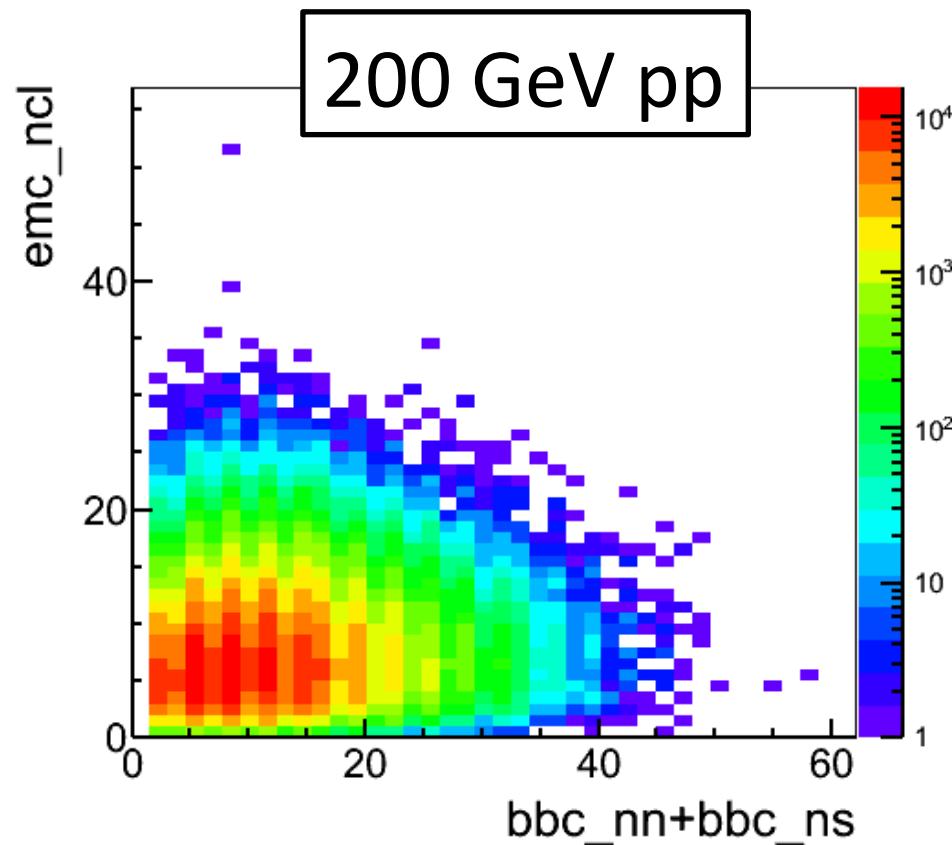
Why not BBC High Multiplicity Trigger works on pp?



Clear correlation btwn central arm activities and BBC multiplicity

-> Works as trigger

14/12/18



Doesn't show strong correlation between BBC and central arm activities

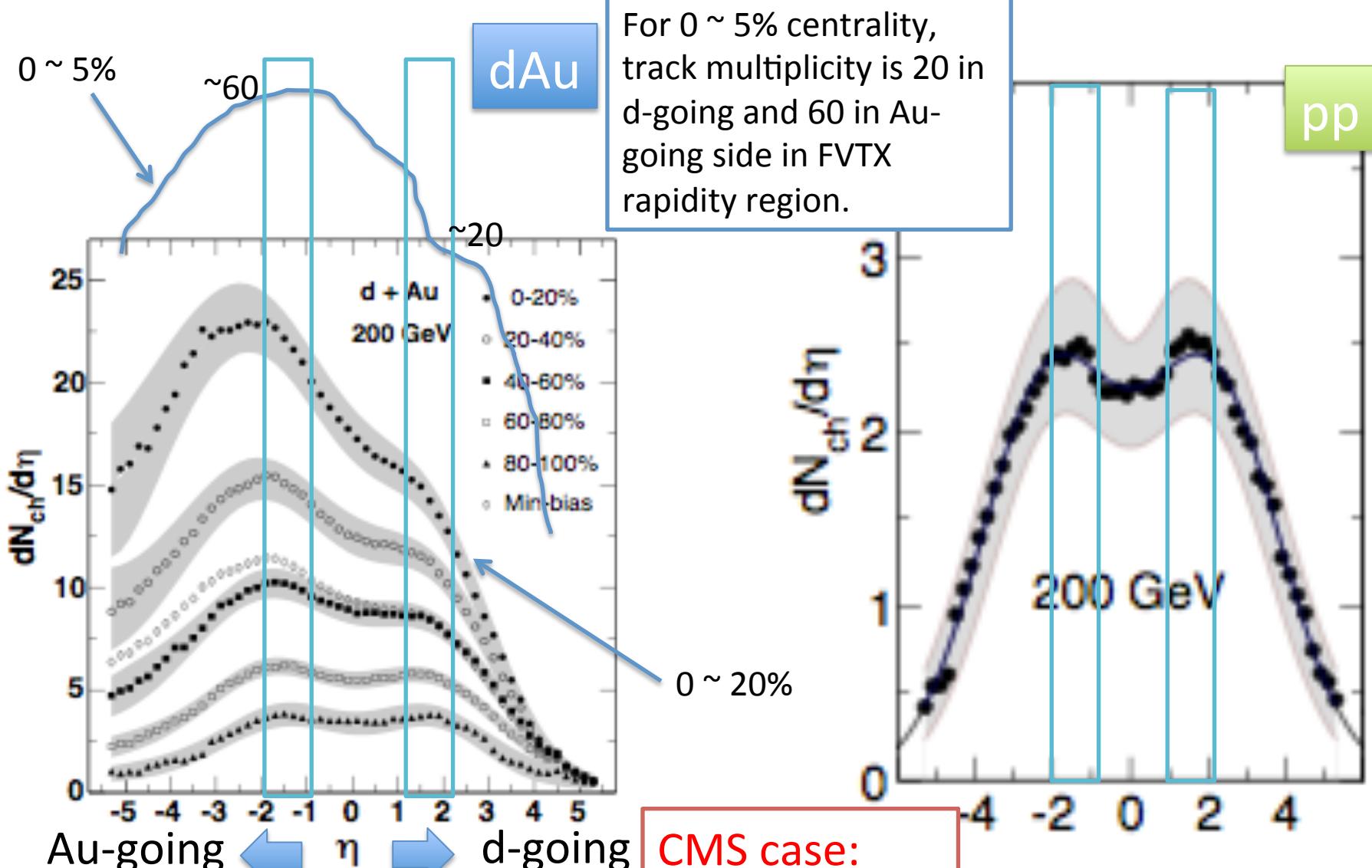
-> Doesn't Work as trigger

Trigger sensitive to high multiplicity

- Central arm : trigger on the number of 2x2 fired cells in the EMCal -> Non azimuthally symmetric -> bias towards v2.
- FVTX Trigger (in preparation) symmetric

FVTX trigger is the best if (collective motion) is seen in FVTX rapidity region. So far the best multiplicity trigger for central arm and MPC region in pp.

Track Multiplicity vs. rapidity



Key features to observe Ridge

- 0-5% dA centrality => **20-60 tracks** / FVTX rapidity unit (Comparable to CMS $dN_{ch}/d\eta \sim 23$)
- In dAu the higher the multiplicity, the v2 component gets stronger.
- **80M events** 0-5% Central dAu in Run8 provided very clear signal.

Key Features to observe Ridge

- 0 ~ 5% centrality => 20 ~ 60 tracks / rapidity unit
- 80 Mevents Central dA Events in Run8

What we gain in Run 15 pp?

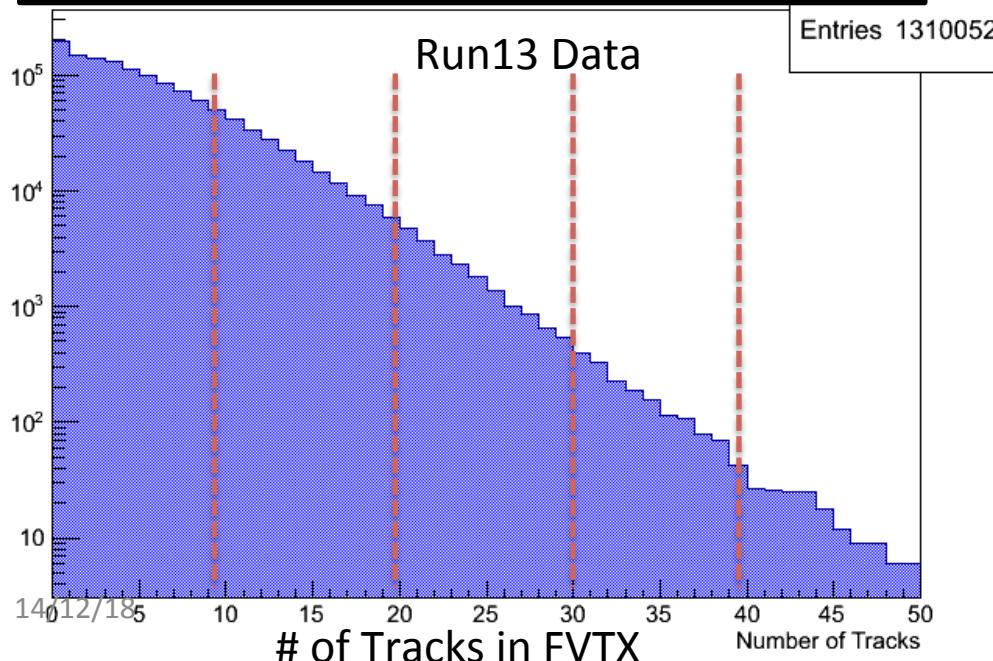
- FVTX North and South separate trigger bits
- Assuming 100Hz per arm (Total 200Hz)
- 200Hz x 3600s x 24h x 7days x 9 weeks x 30%
Up time ~ 300M high multiplicity events

$$\# \text{trigger}(\# \text{track} > 30) = \# \text{trigger} \times \text{purity}$$

Required Rejection Power

# of Tracks / arm	> 0	> 10	> 20	> 30	> 40
Fraction in MB	100%	10%	0.7%	0.04%	0.008%
Rates in MB	1MHz	100kHz	7kHz	400Hz	80Hz
Required Rejection Power	1	10	142	2,500	12,500

of Raw Tracks in FVTX / arm @ 510GeV pp



Real Track : Basic cut/Raw track,
200GeV/500GeV to be scaled

If we ask coincidence with BBC
(narrow), then gain x4 RP

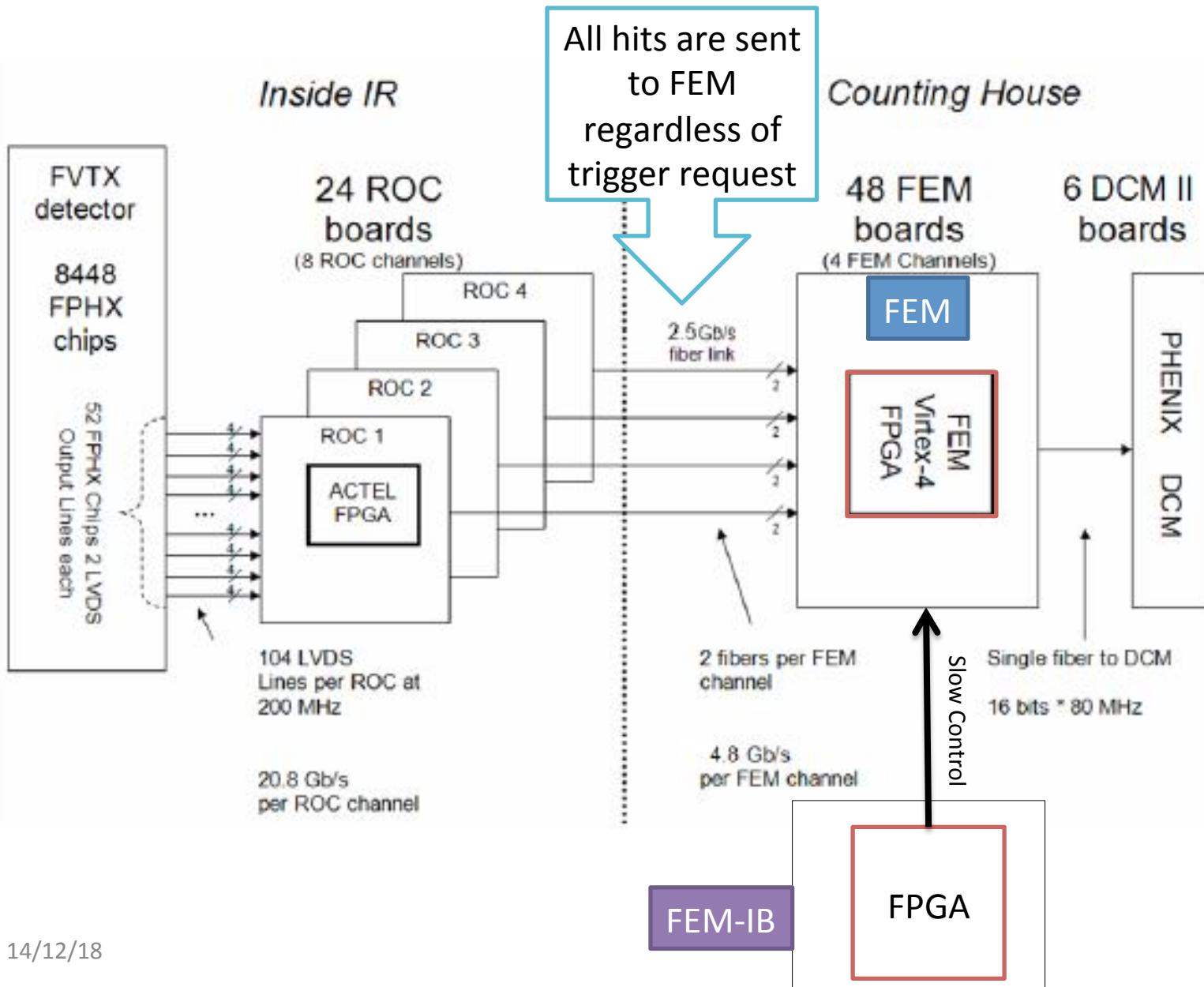


Required rejection ~ 1000

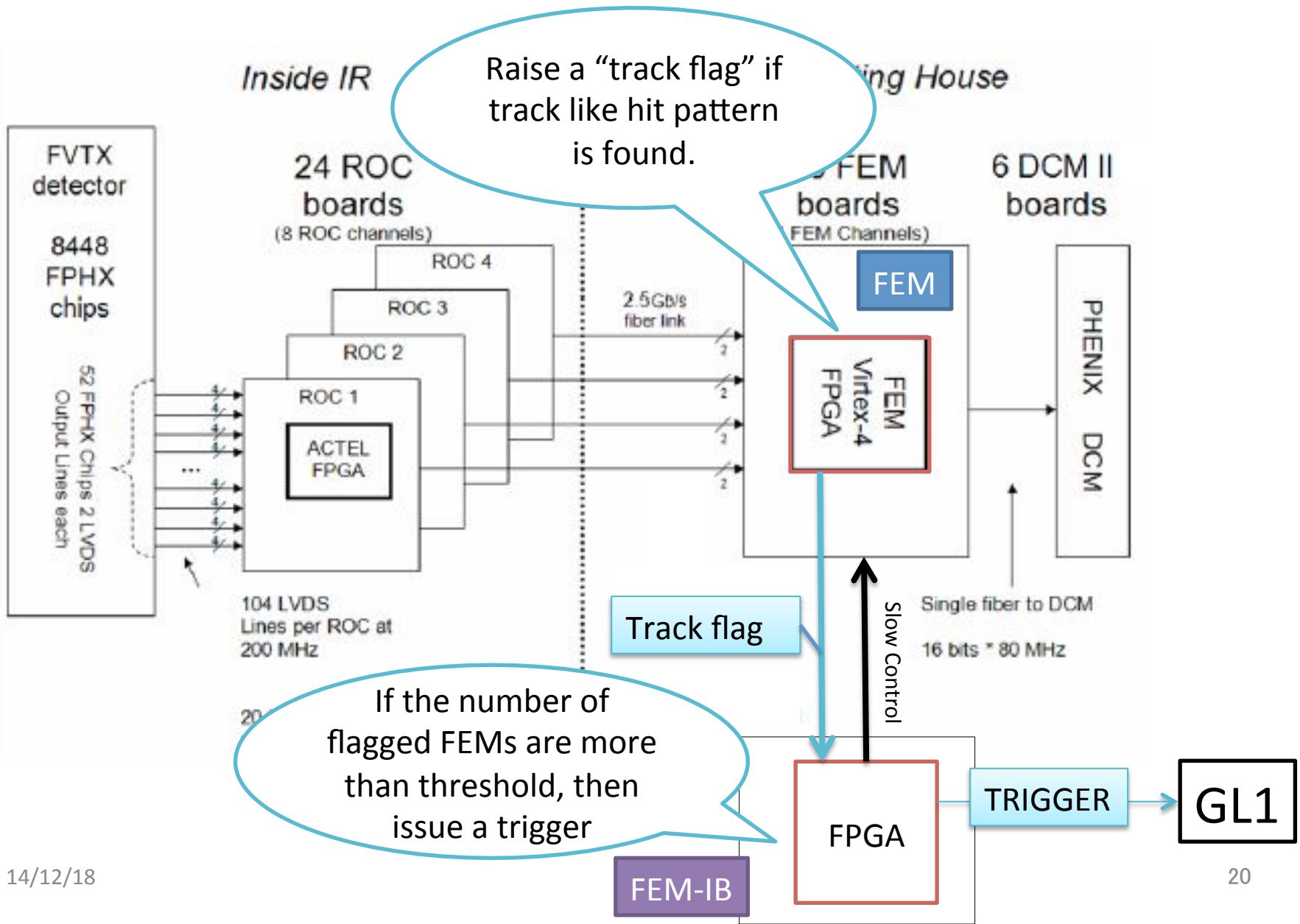
Terminology

FVTX READOUT AND TRIGGER LOGIC

FVTX Readout

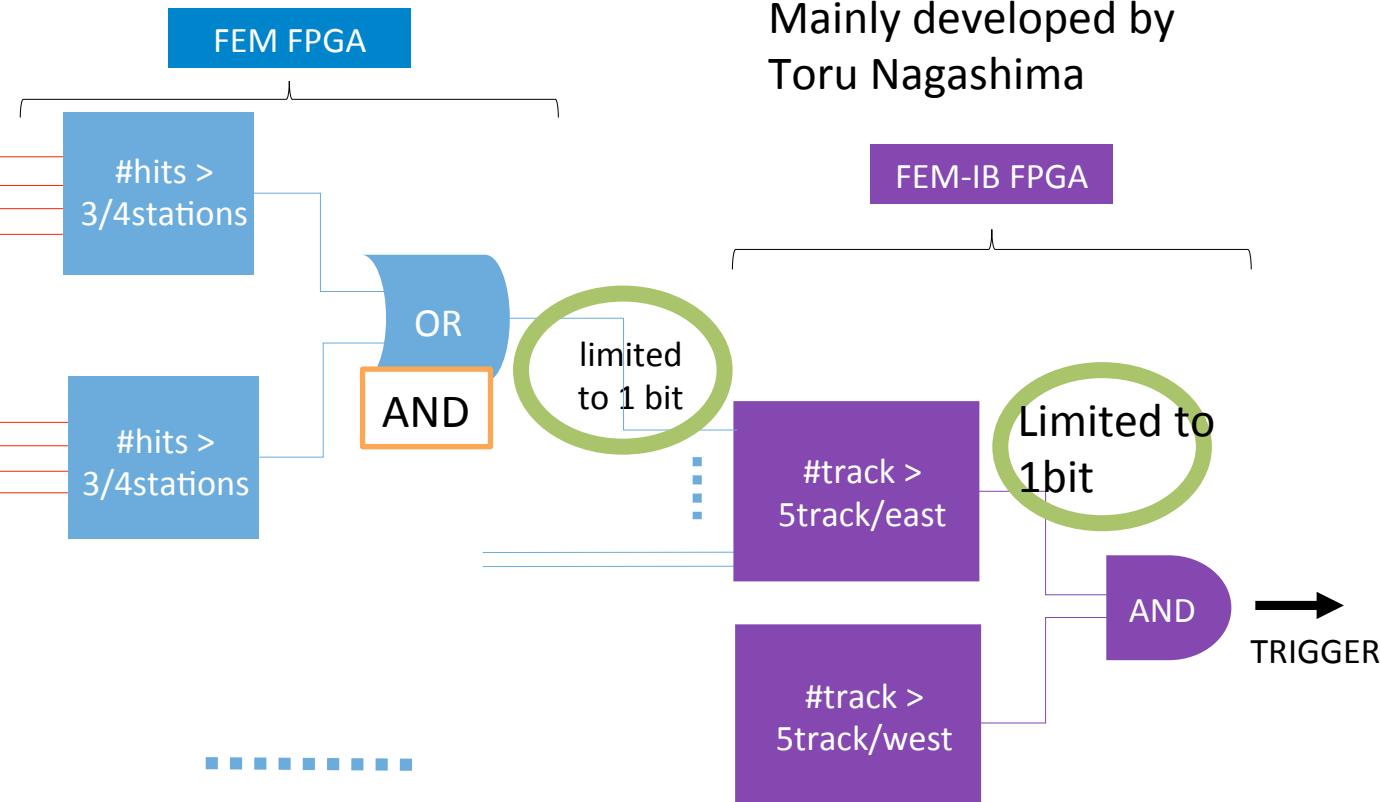
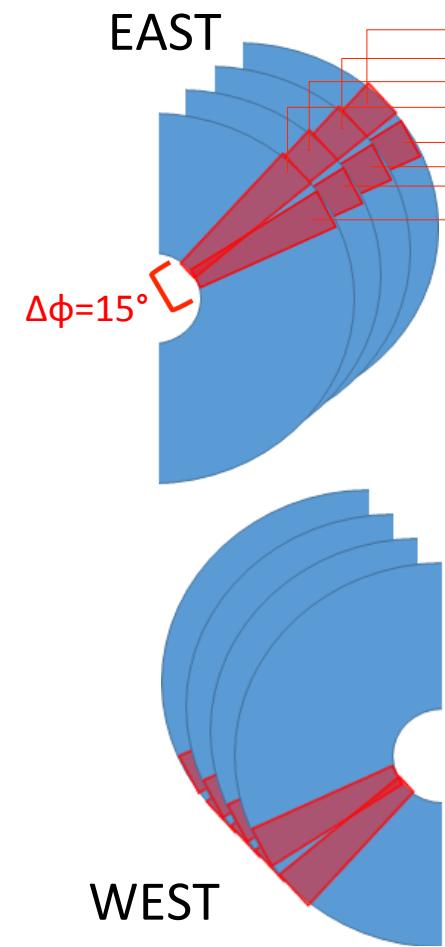


FVTX Trigger Design



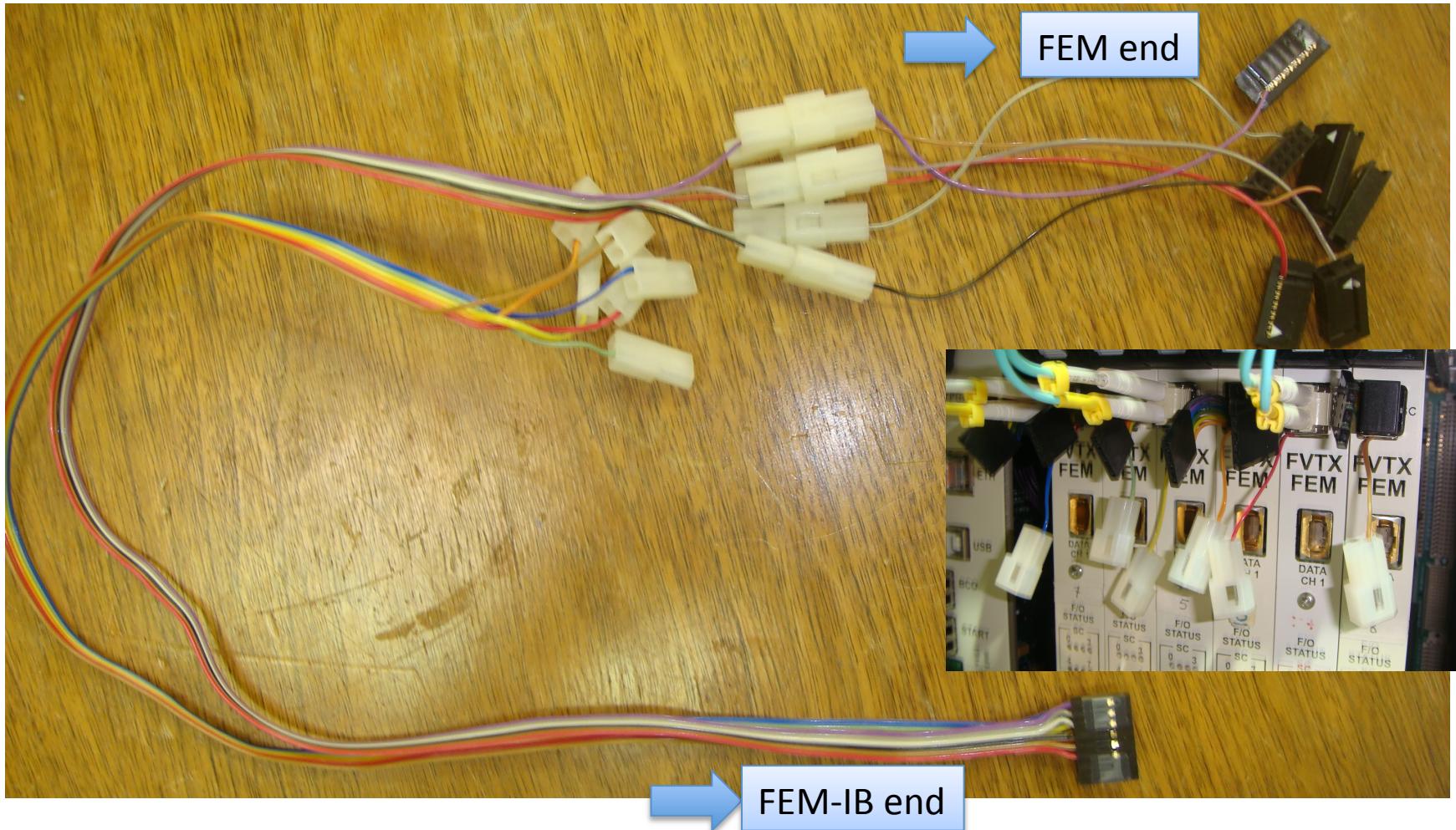
Mainly developed by
Aaron Key (UNM)

Mainly developed by
Toru Nagashima



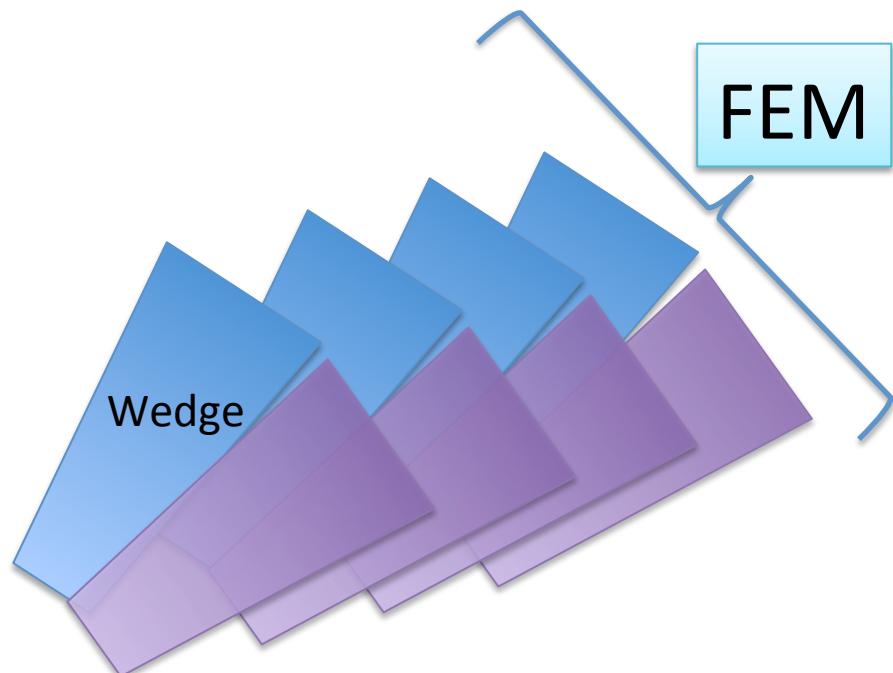
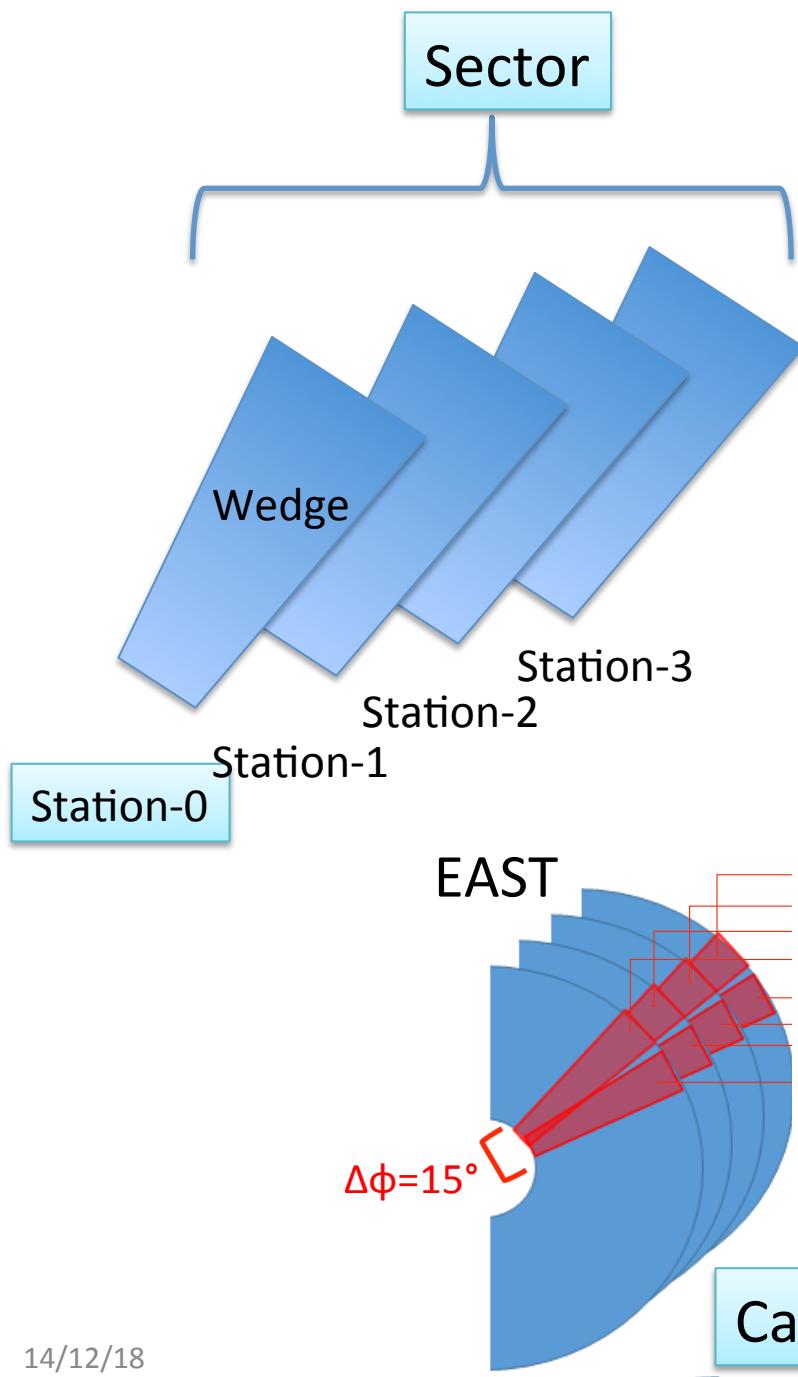
- At least one hit in 3 out of 4 stations is required within a half sector ($(\Delta\phi=7.5^\circ)$). \rightarrow TrackFlag.
- If there are more than two tracks within a given sector ($(\Delta\phi=15^\circ)$), the second one won't be counted.

FEM-IB Cable

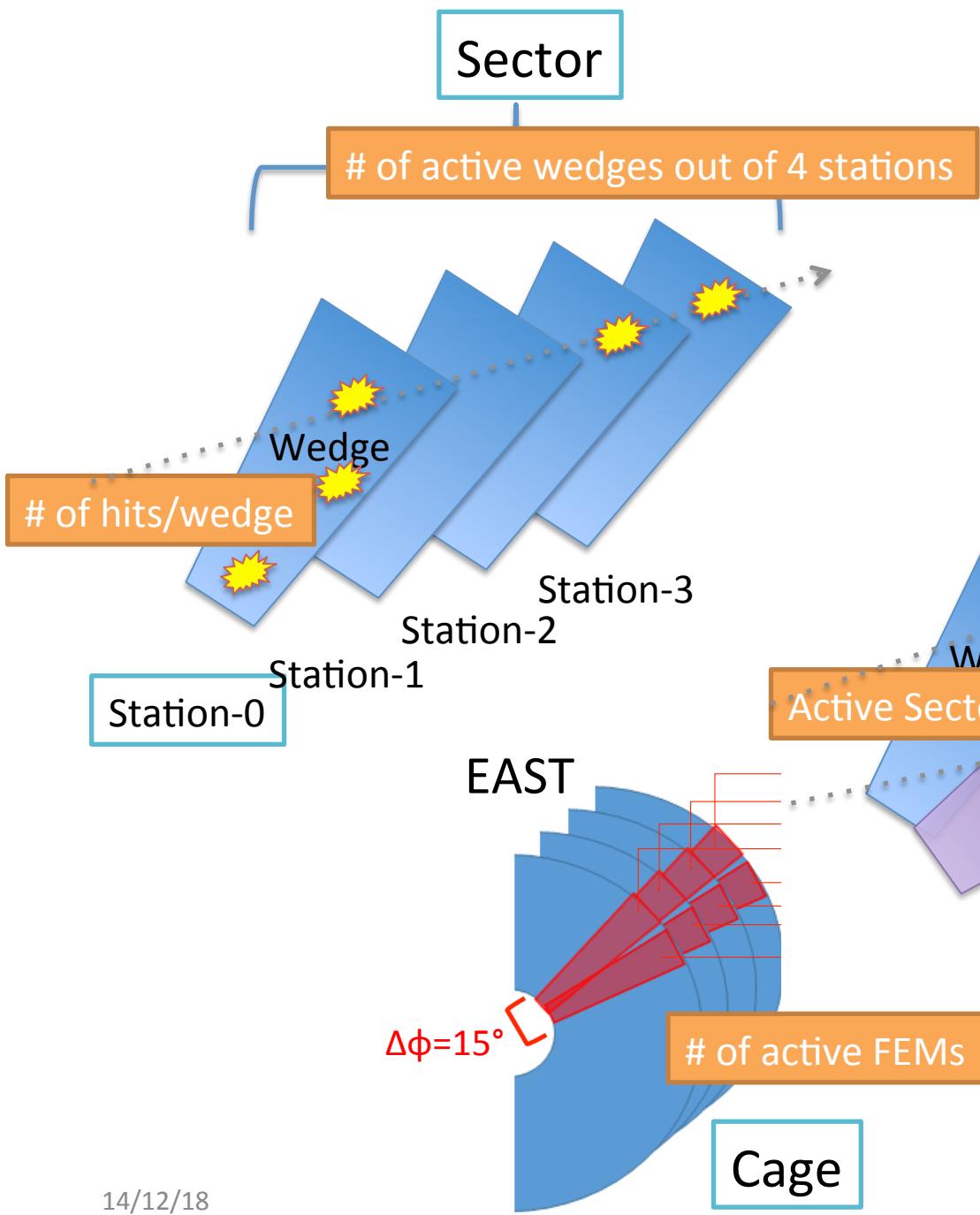


Cables are connected between FPGA test pins between FEM and FEM-IB.
FEM cables are installed in November.

FVTX Terminology



FVTX Trigger Parameters

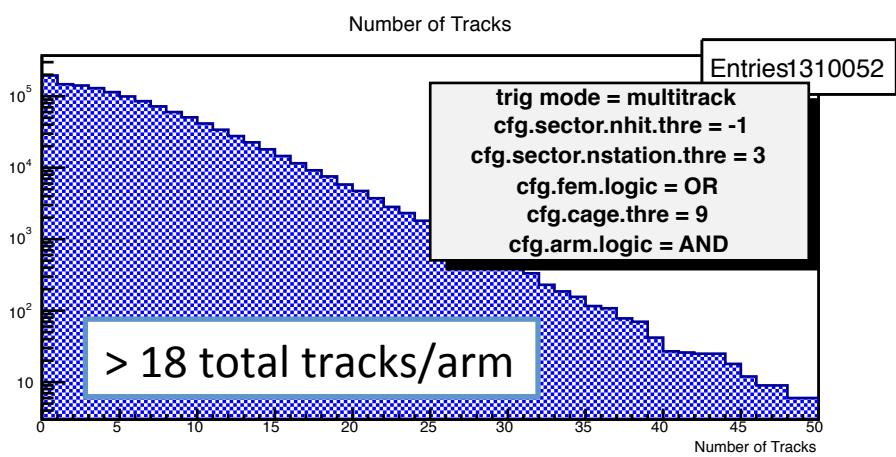
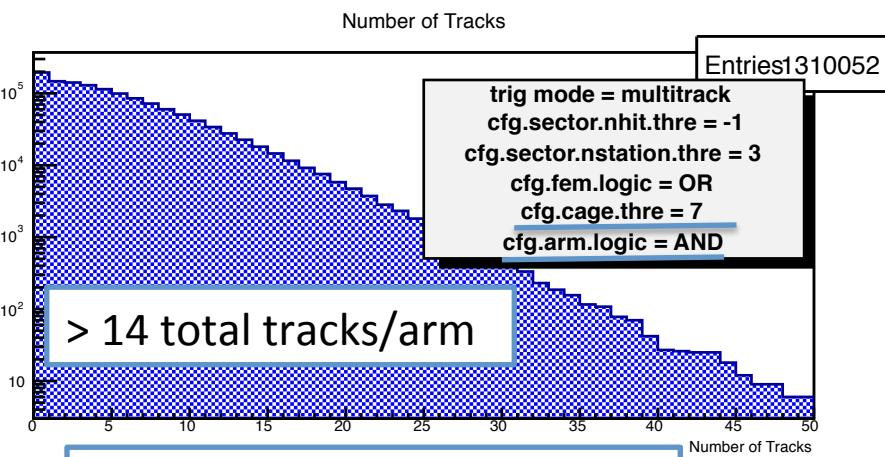


Arm

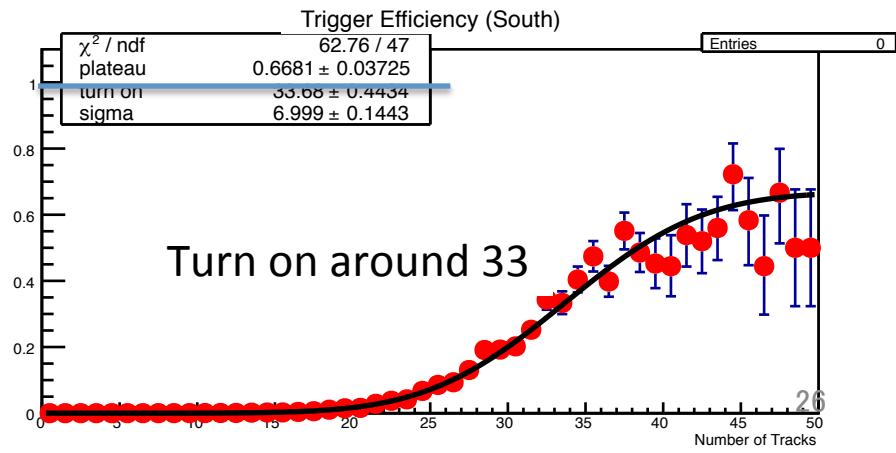
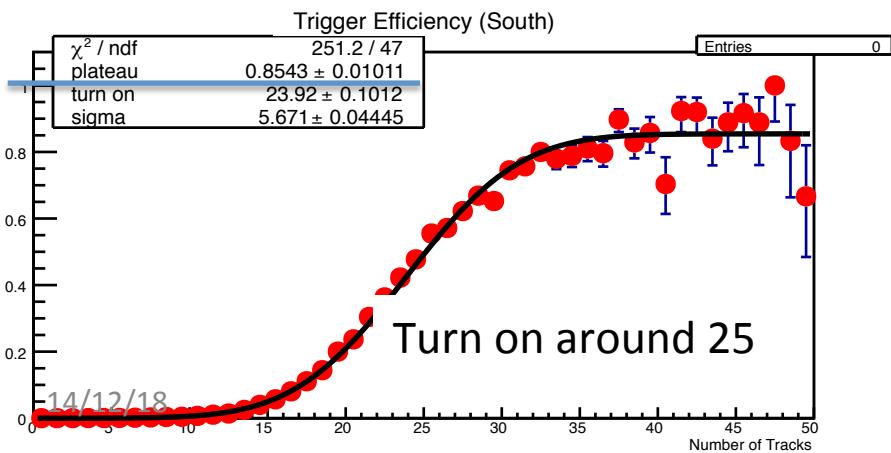
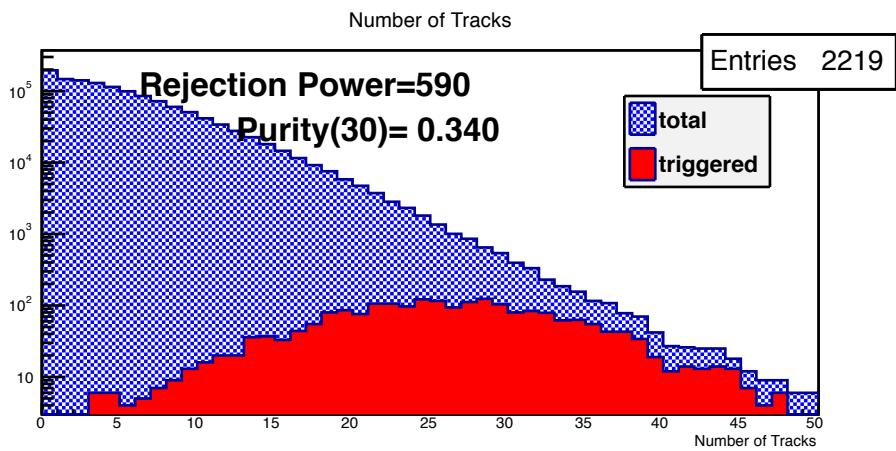
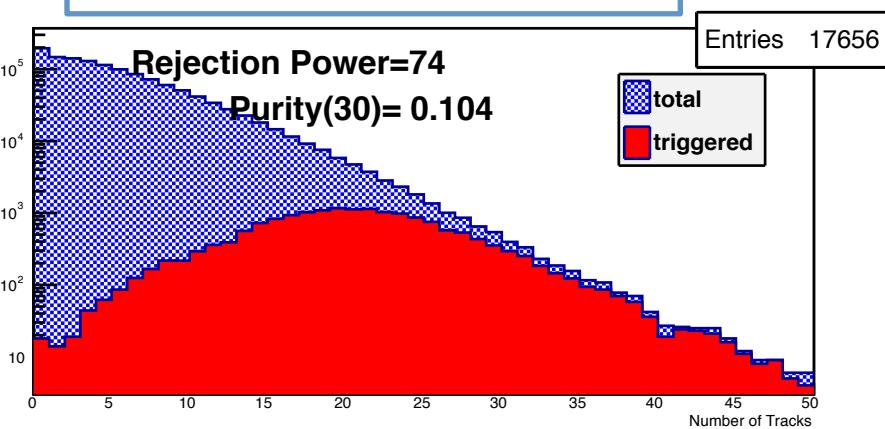
Active Cage (AND/OR)

Run13 pp data was used. #of tracks could be lower in 200GeV.

TRIGGER PERFORMANCE



Number of Track Distribution



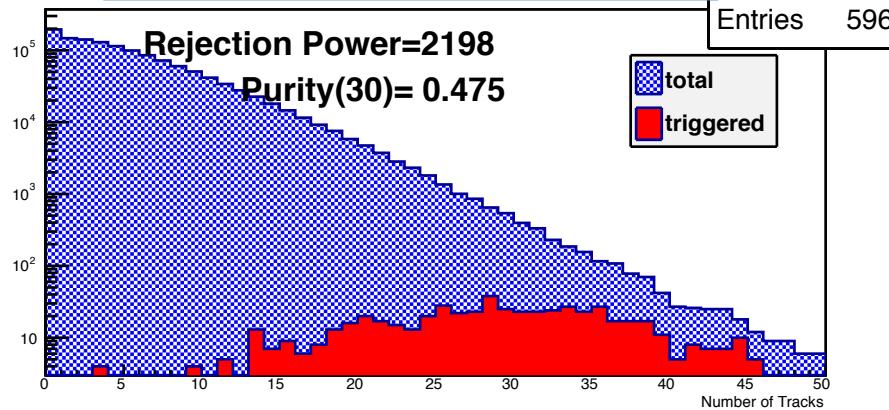
Number of Tracks

Entries 1310052

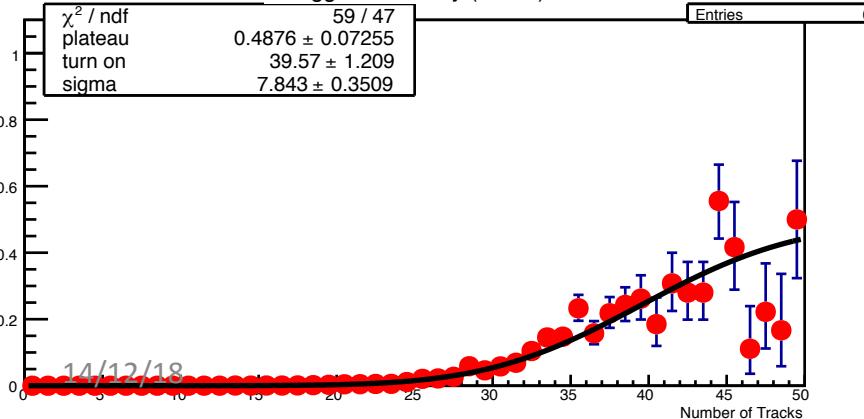
trig mode = multitrack
 cfg.sector.nhit.thre = -1
 cfg.sector.nstation.thre = 3
 cfg.fem.logic = OR
 cfg.cage.thre = 10
 cfg.arm.logic = AND

> 20 total tracks/arm

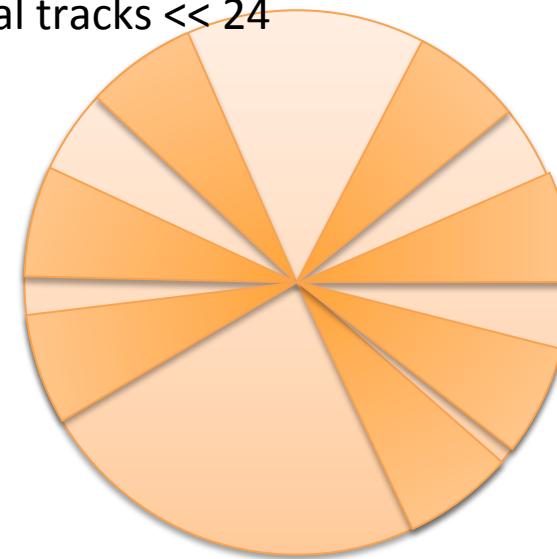
Number of Track Distribution



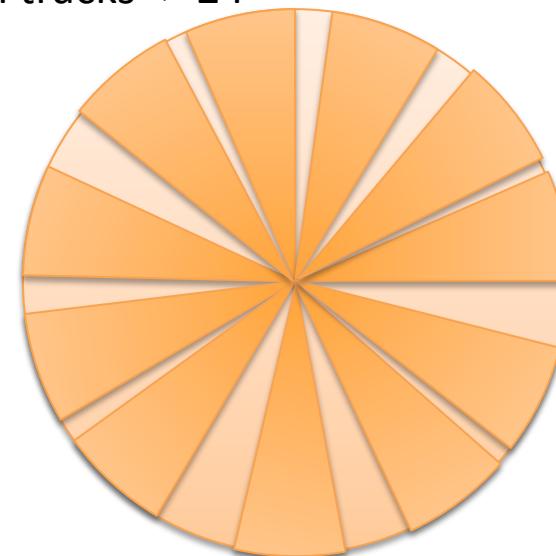
Trigger Efficiency (South)



Total tracks << 24



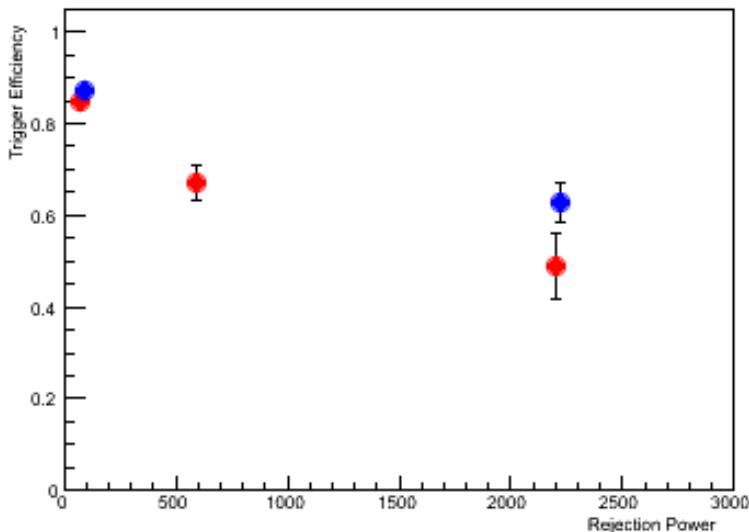
Total tracks -> 24



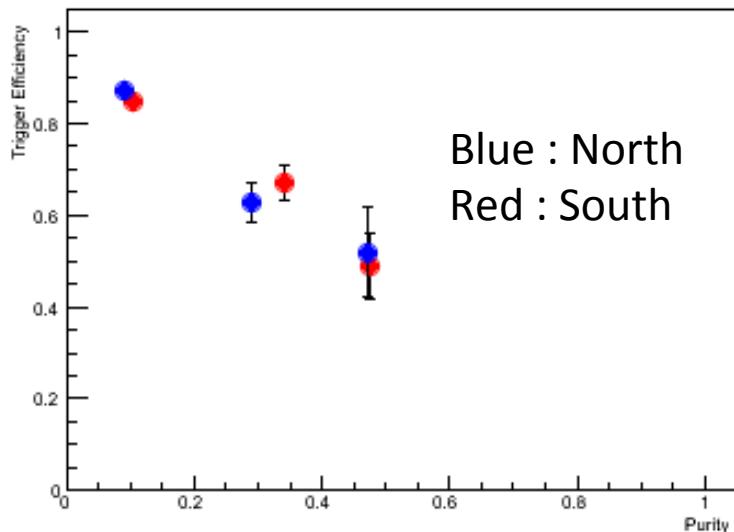
Biased towards v0

Trigger Performance

Eff_vs_RP

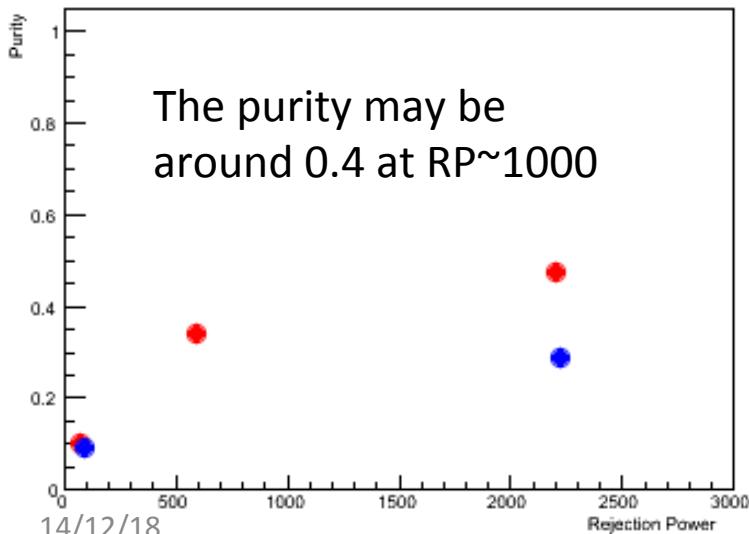


Eff_vs_Purity



Blue : North
Red : South

Purity_vs_RP



trig mode = multitrack
cfg.sector.nhit.thre = -1
cfg.sector.nstation.thre = 3
cfg.fem.logic = OR
cfg.cage.thre = 7 ~ 10
cfg.arm.logic = AND

FVTX Trigger Performance

- Rejection power of 500 and purity of 0.4 has been demonstrated. If we ask coincidence with BBC narrow, which brings to the ball park of required RP.
- Higher rejection power is achievable but could be trade off with introducing the trigger bias.
- Optimization of algorithm is underway. North & South Rejection Power is also to be studied.
- The present purity 0.4 scales down expected total events from 300M to 120M. Further scale down by
 - Multiplicity(200GeV)/Multiplicity(500GeV)
 - Basic cut track / Raw track
 - Etc.

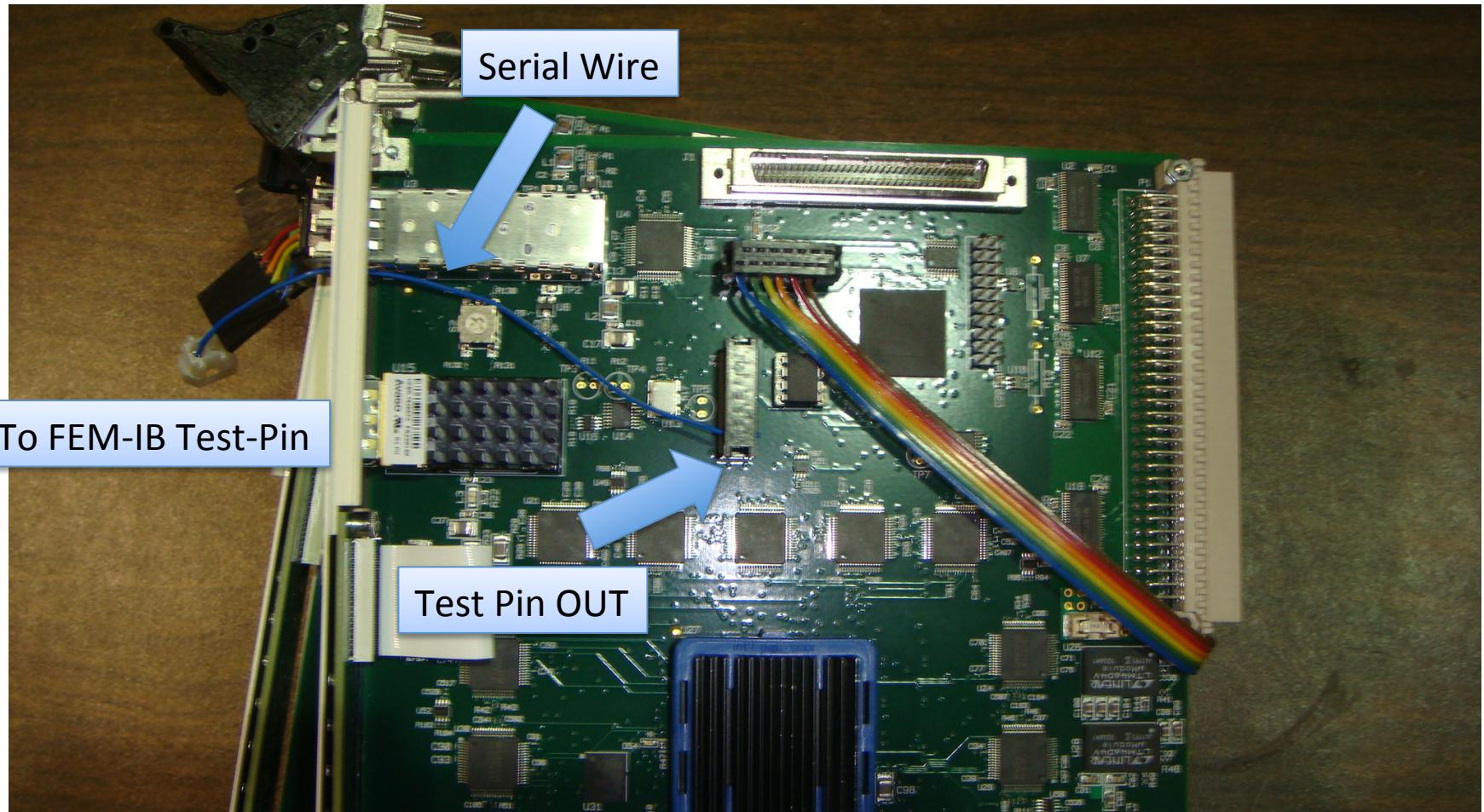
Summary

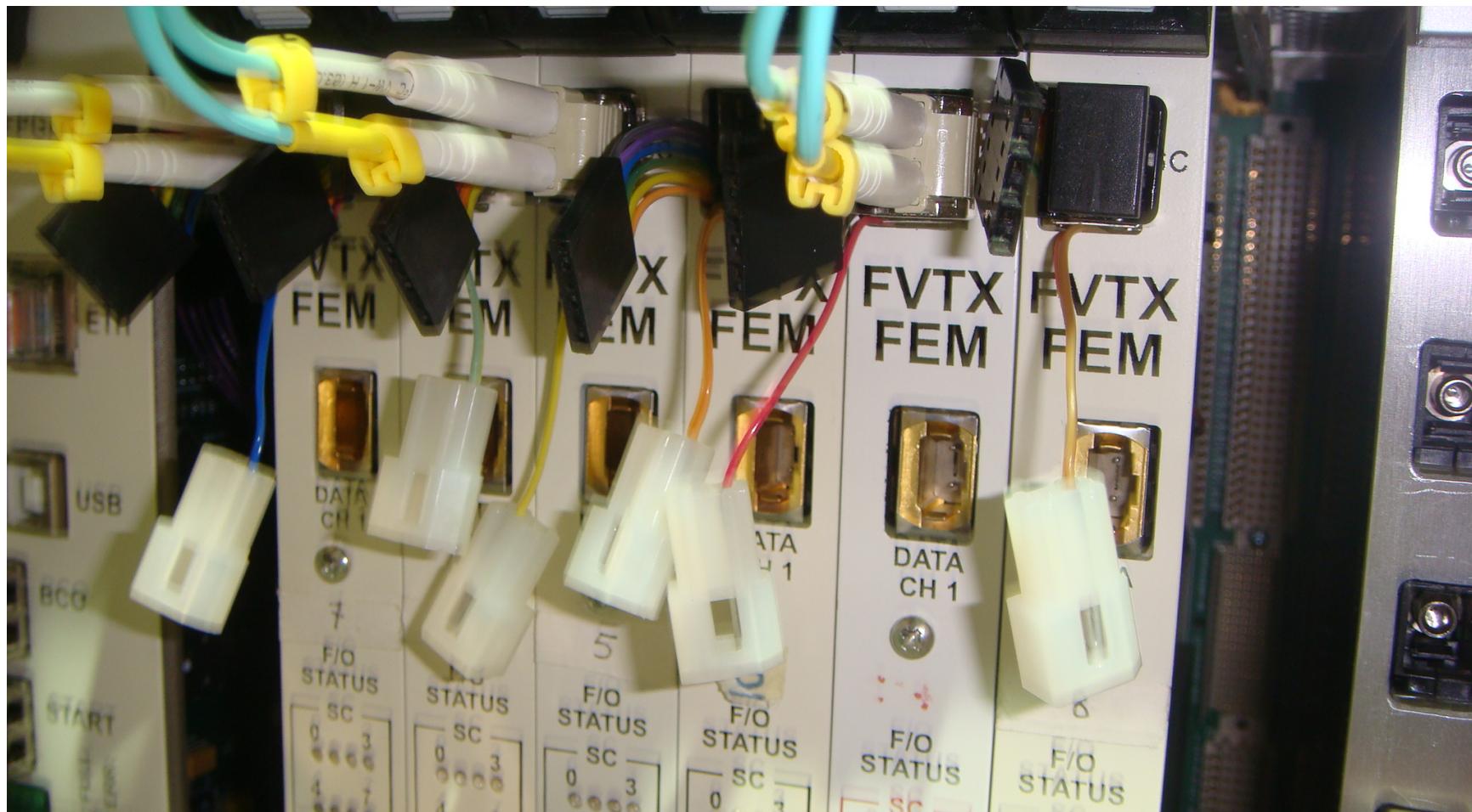
- We propose high multiplicity trigger to be implemented to existing FVTX detector.
- Hardware for the trigger are mostly installed already. No new electronics boards are necessary.
- We can collect high multiplicity event samples similar to Run8 dAu 0-5% centrality events with ~ 200 Hz bandwidth. (to be scaled down by 200/500GeV multi, basic cut/raw, etc).

BACKUPS

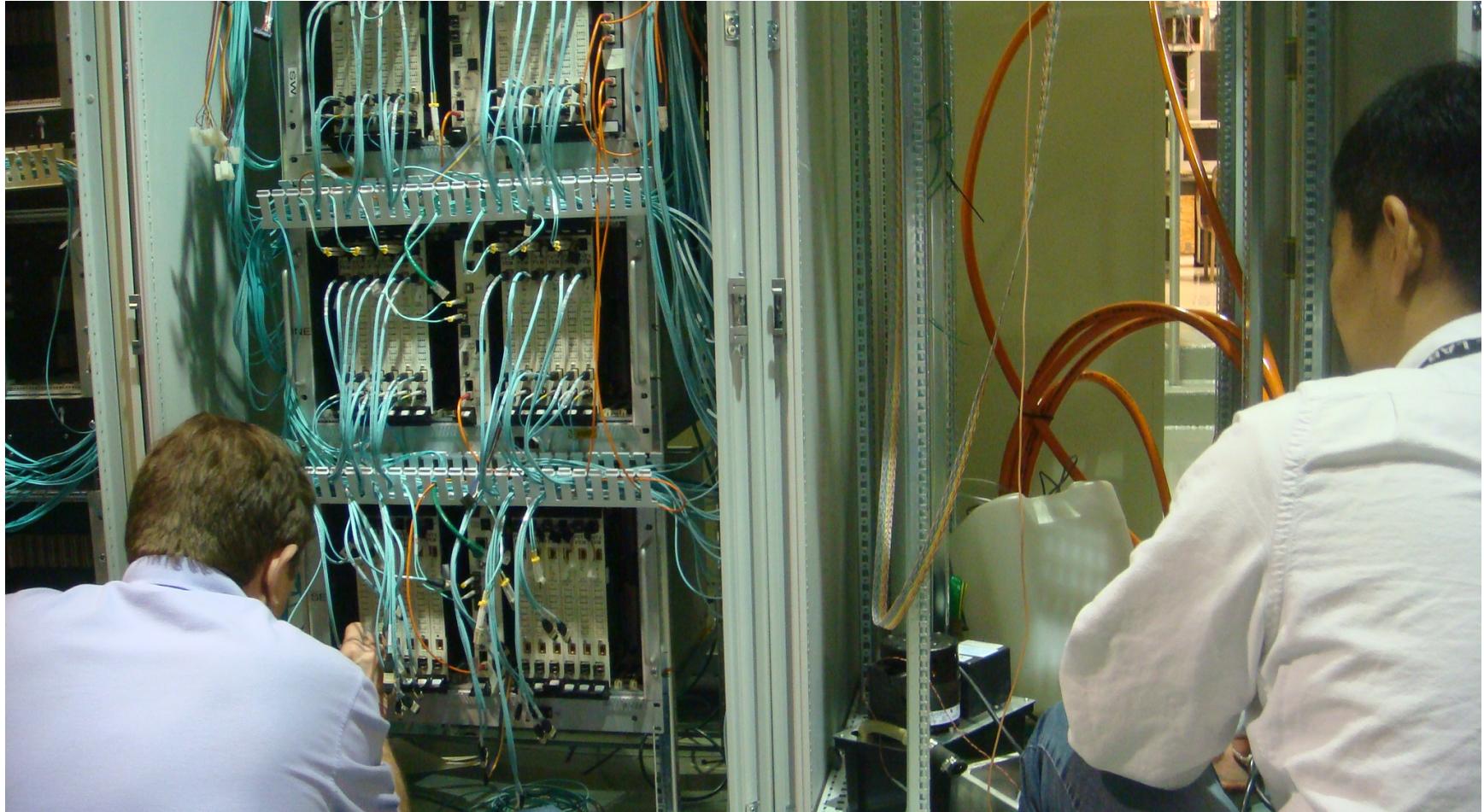
HARDWARE STATUS

Trigger Cable @ FEM Board



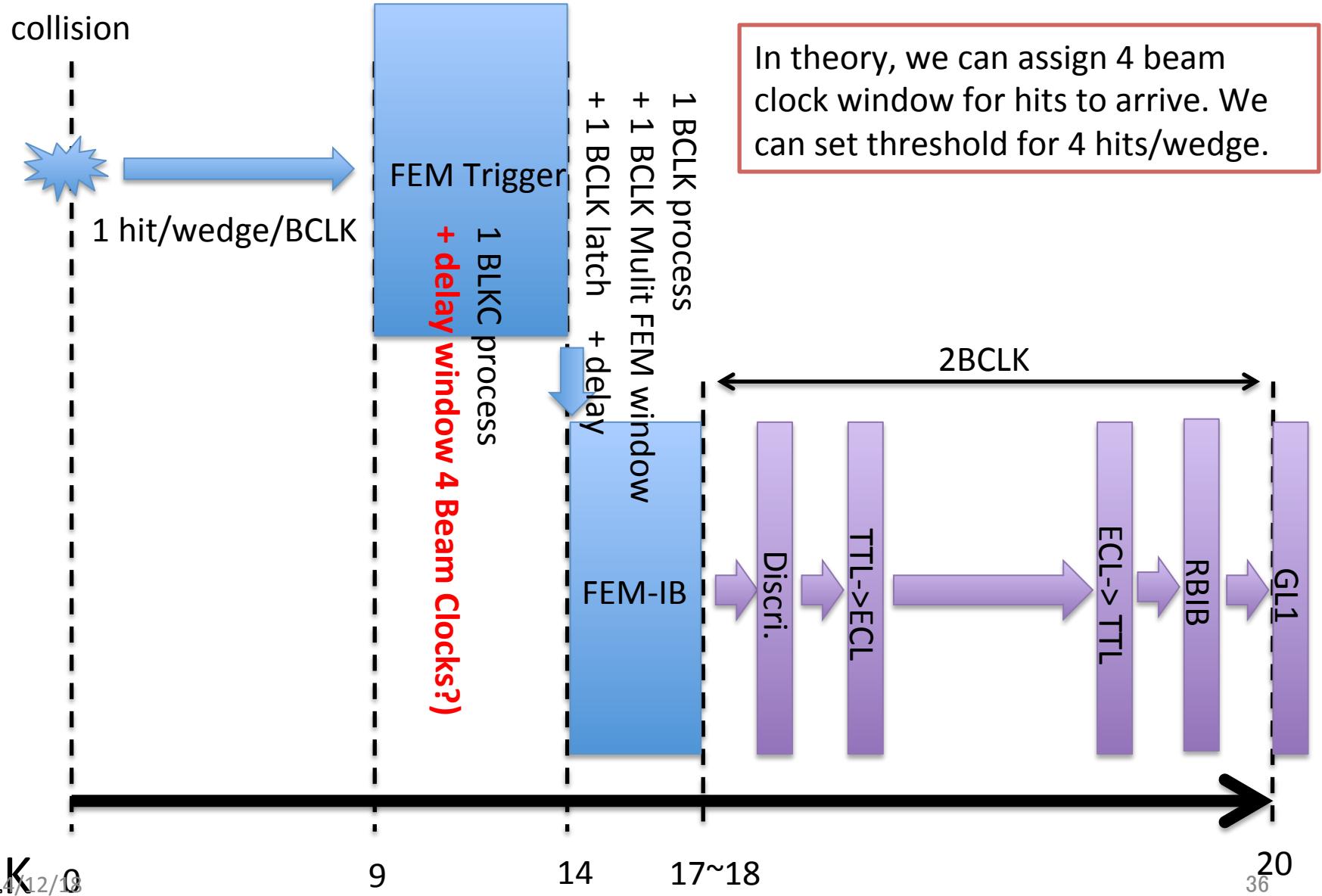


FEM -> FEM-IB Installation



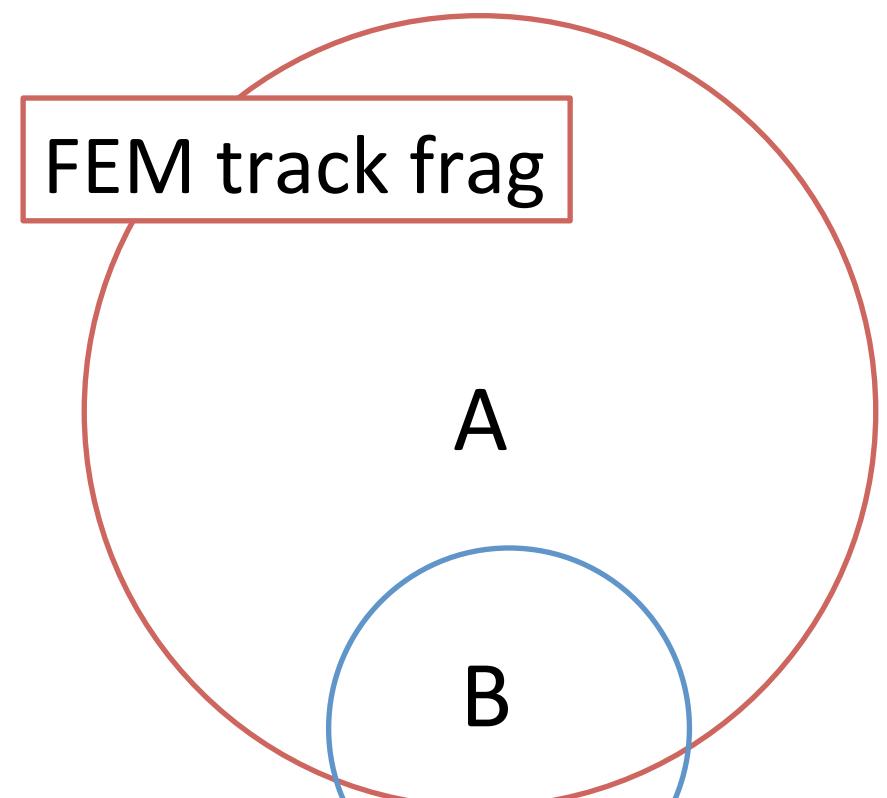
November 5th, 2014

FVTX Trigger Timing Chart

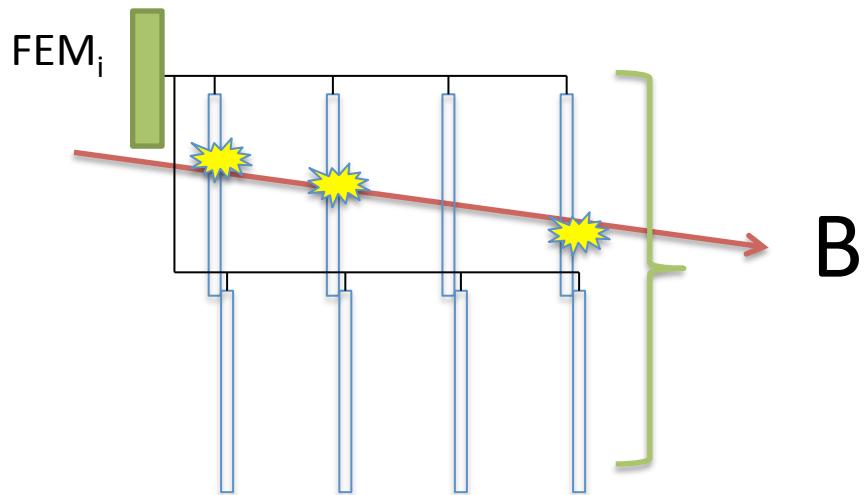


DIFFERENCE BETWEEN ONLINE AND OFFLINE TRACK

Difference in Track Criteria

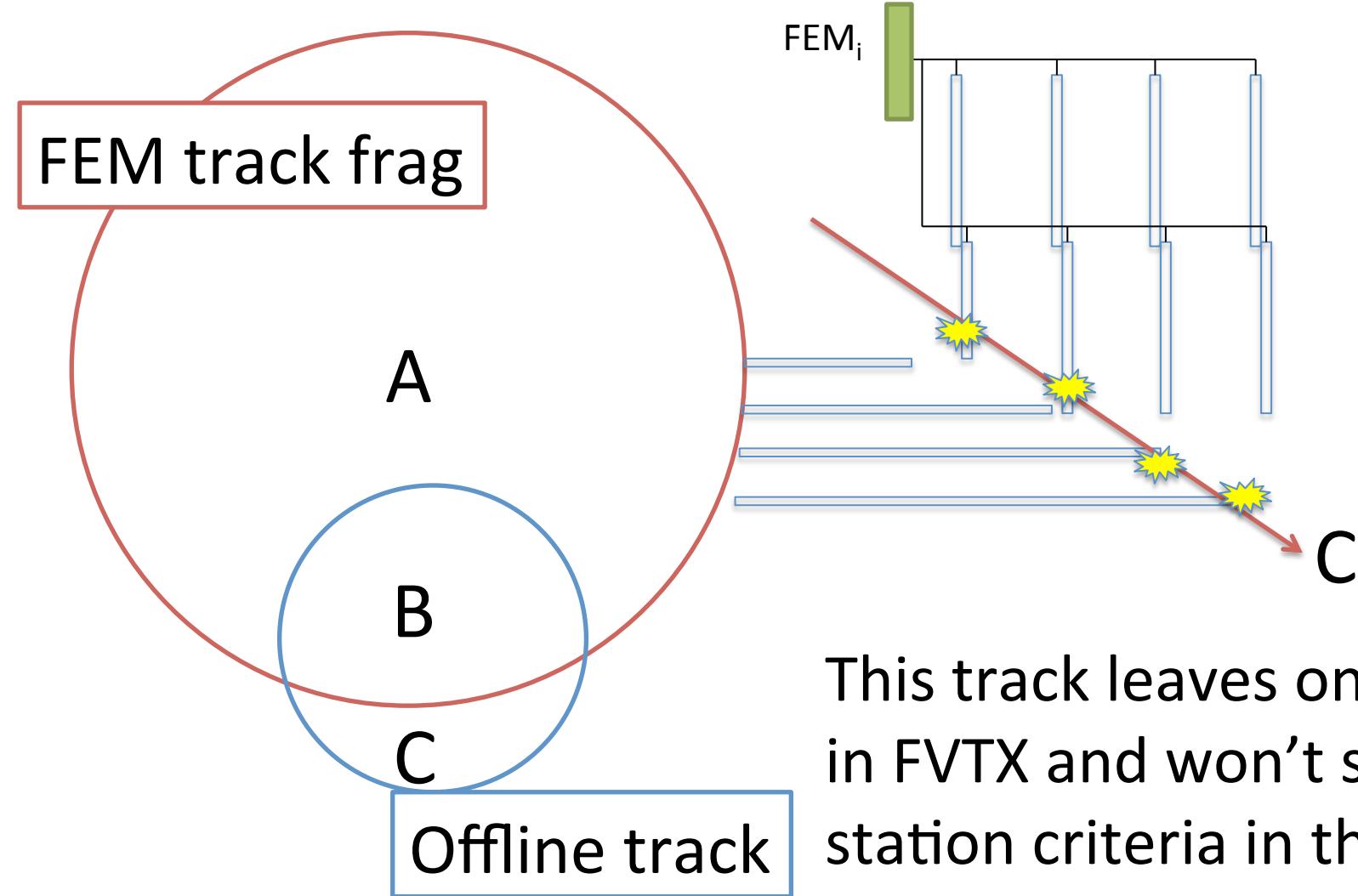


This category won't
be picked up by the
trigger -> cause of
survival tracks

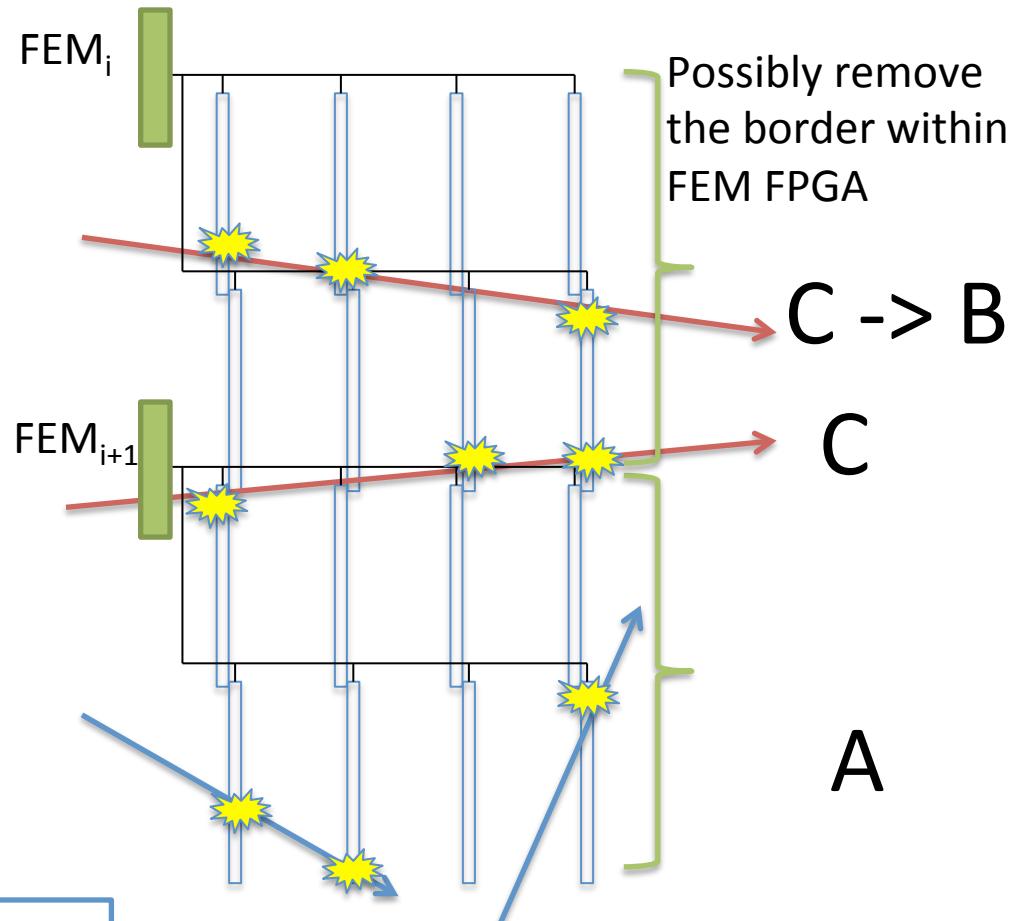
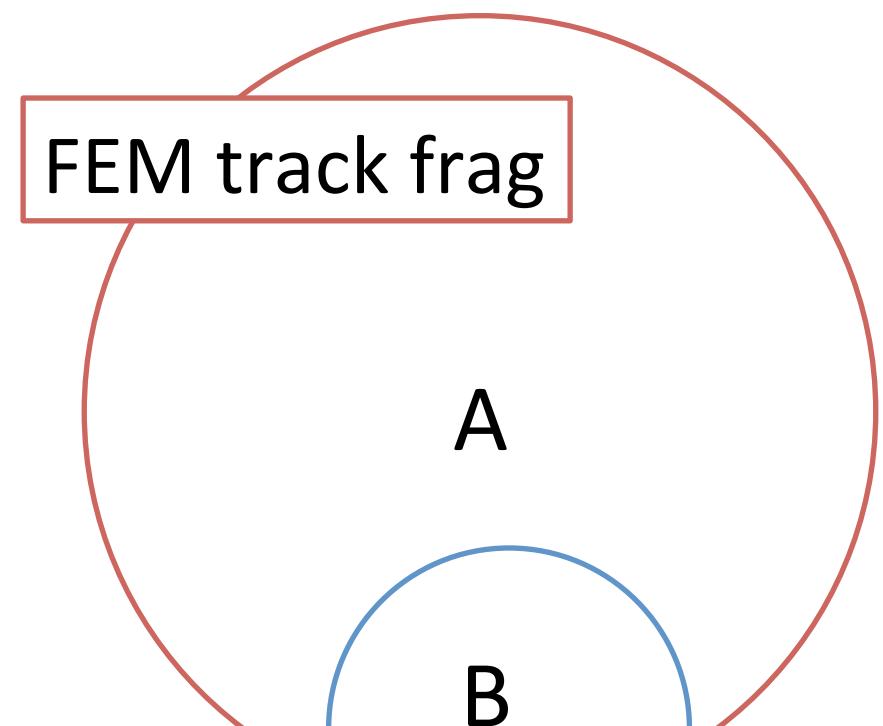


This track will be
recognized as track in
both online and offline.

Difference in Track Criteria

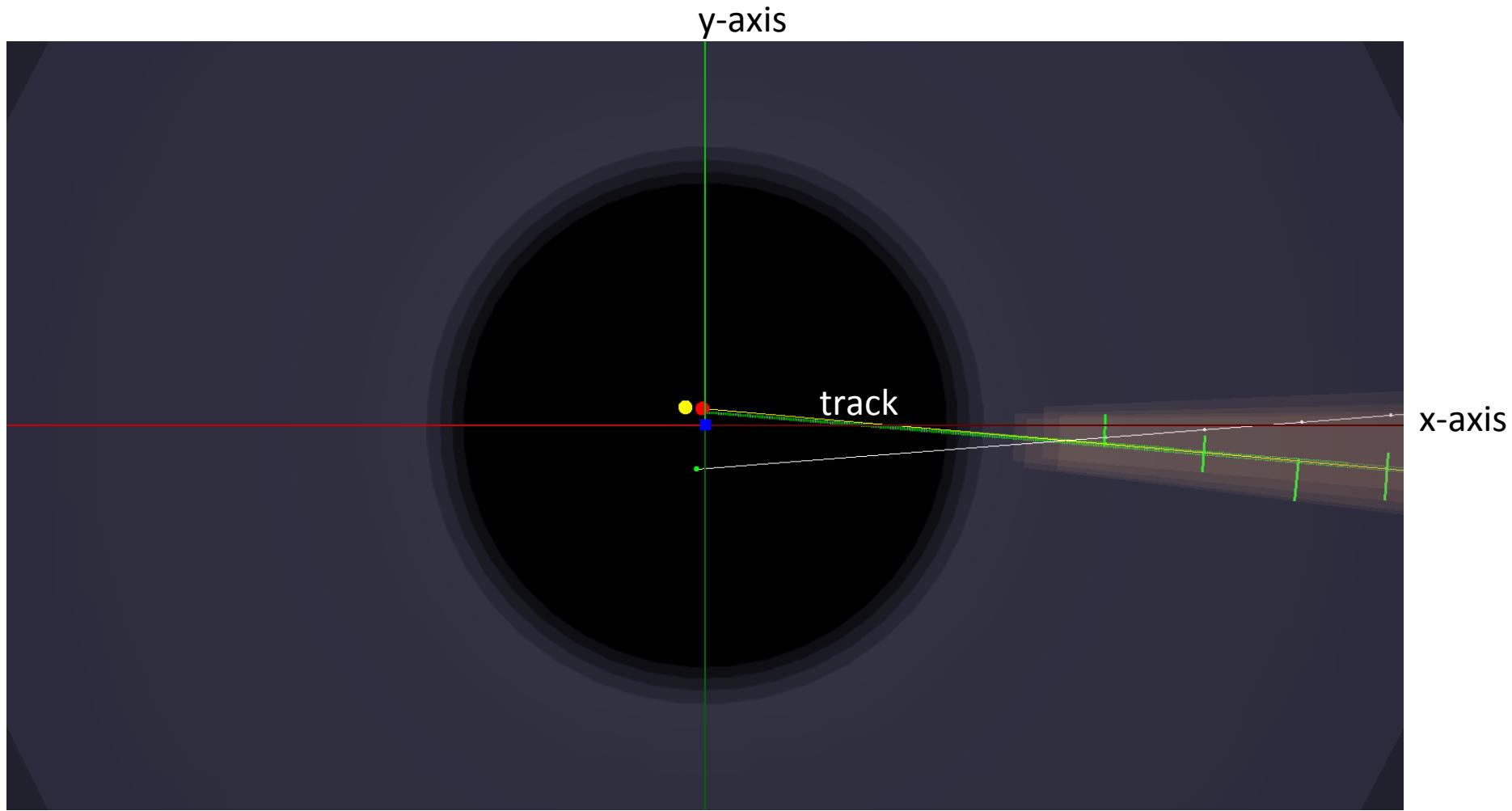


Difference in Track Criteria

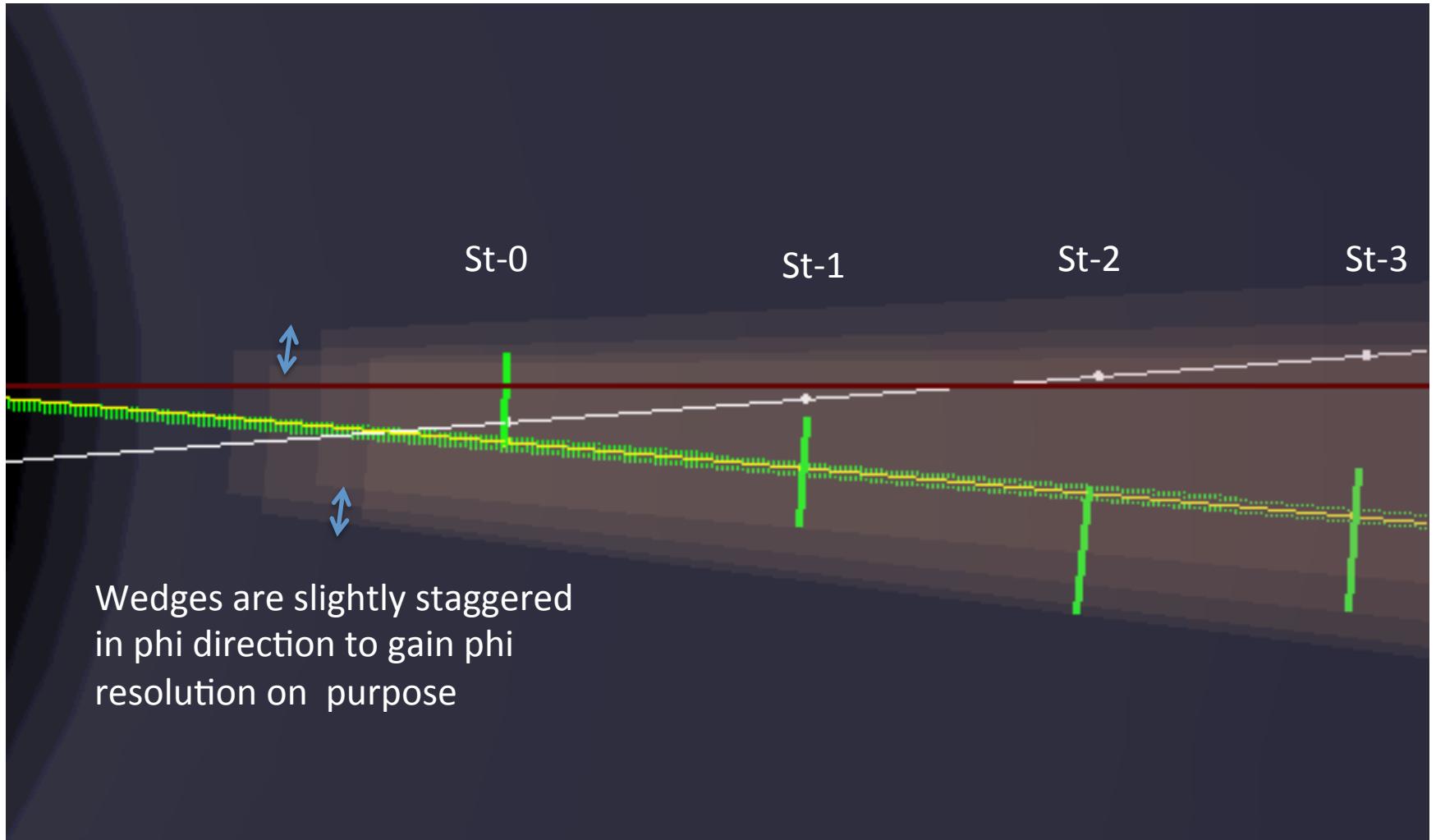


- This differences can cause small fraction survives FEM track frag>x trigger condition

FVTX Alignment



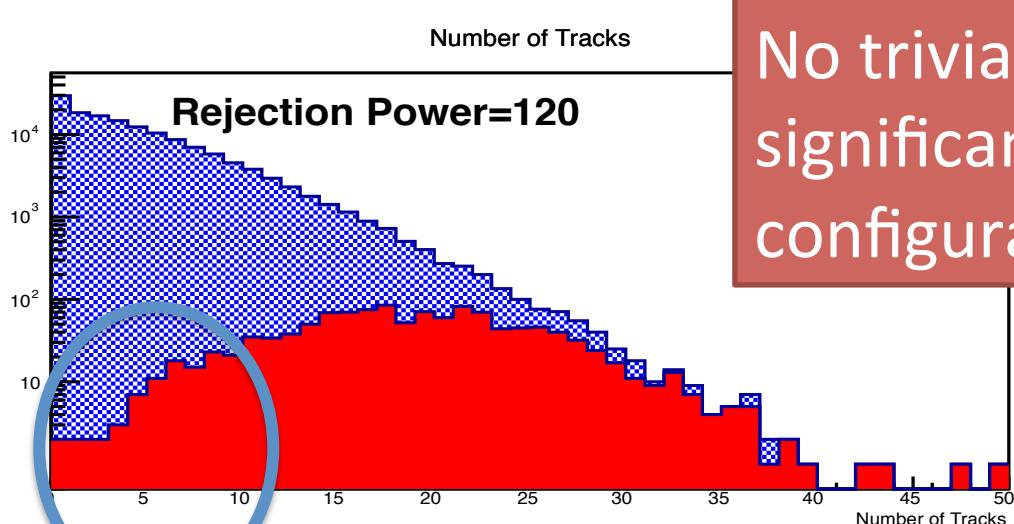
FVTX Event Display



14/12/18 This mismatch of phi angle between stations enhances “category C”

Low # Track Leak Cause Summary

1. Online trigger won't recognize track which crosses boarder between sectors
2. Online trigger won't have VTX hit information.
3. FVTX stations are staggered by a little bit in phi direction



No trivial solutions without significant revise in hardware configuration

Multiplicity in pp (UA1)

NPB335(1990)261

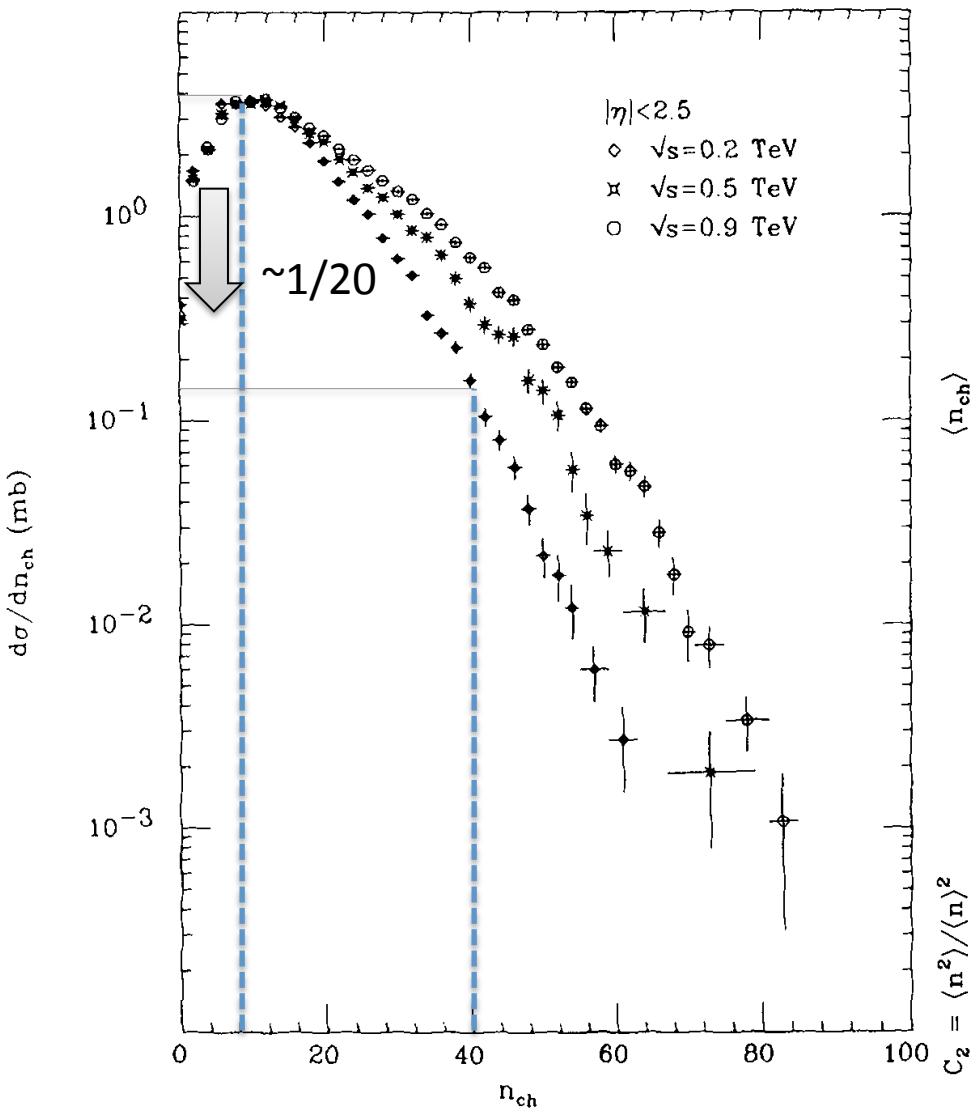
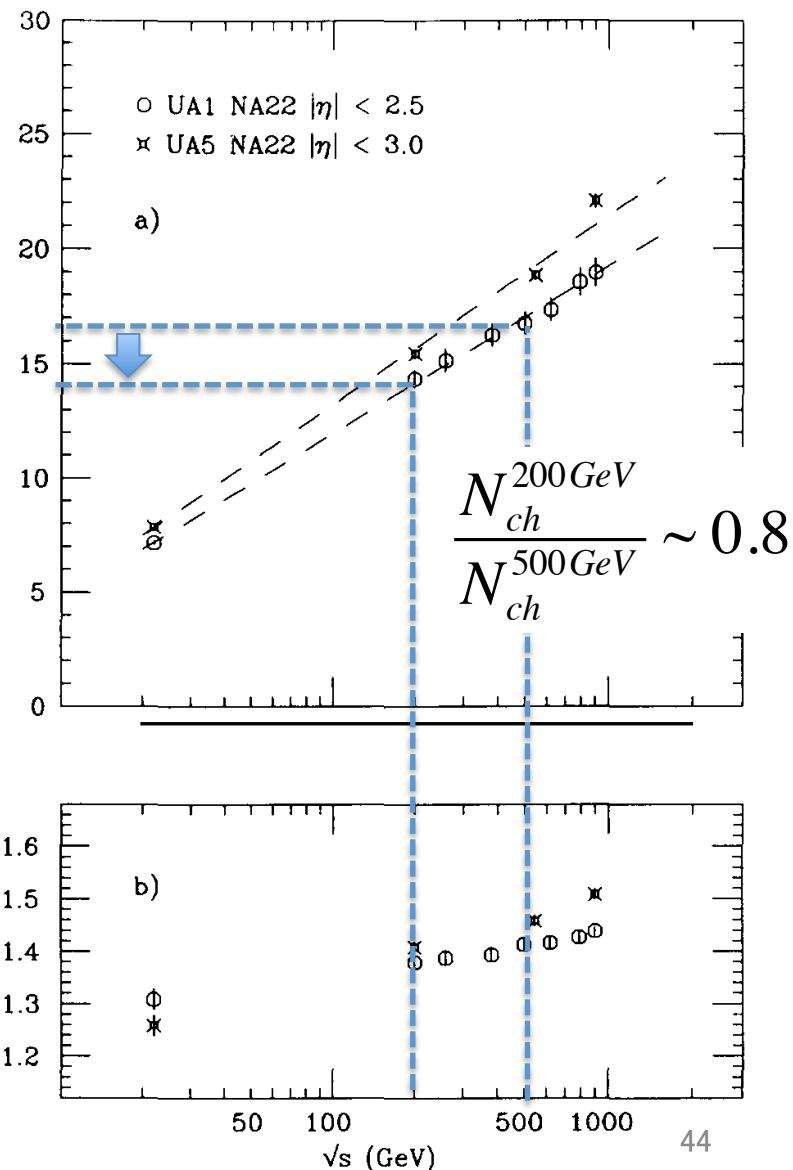
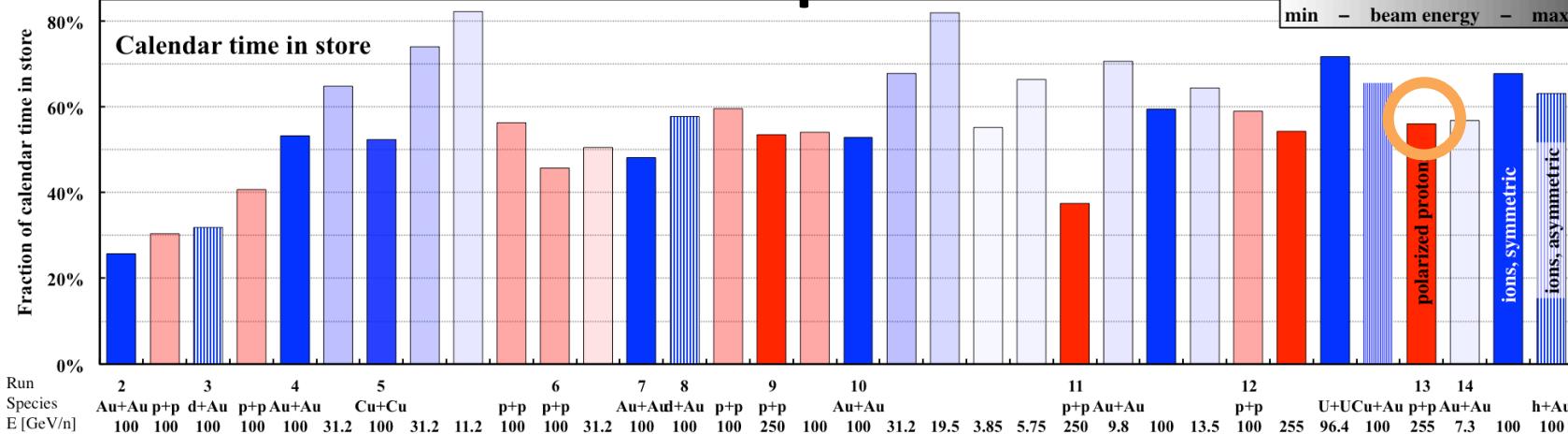


Fig. 3. Topological cross sections for $|\eta| < 2.5$ as a function of the charged particle multiplicity.

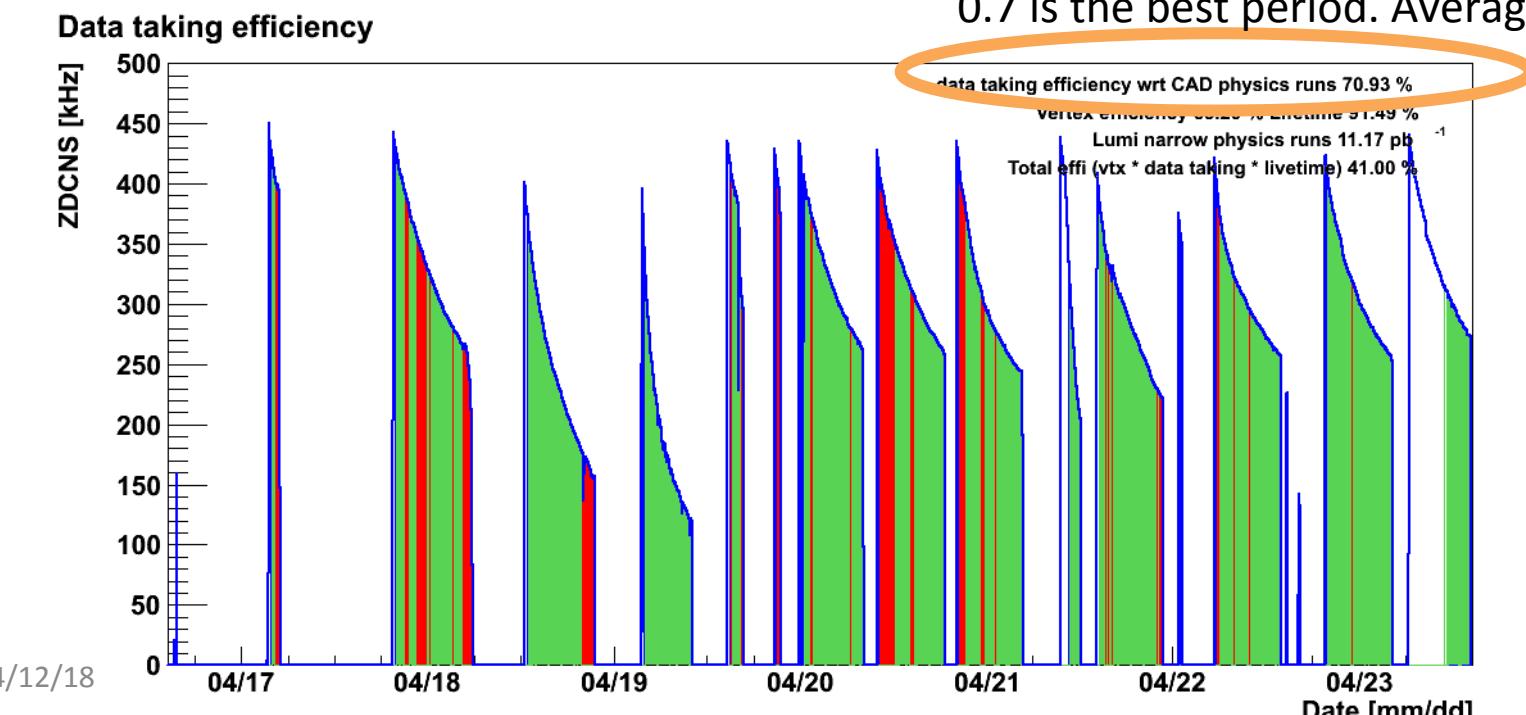
UA1 Collaboration / $p\bar{p}$ collisions



RHIC x PHENIX Uptime Estimation



$0.55 \times \text{phys/store}$ $0.7 = 0.38 \times \text{phys/store}$
0.7 is the best period. Average ~ 0.6 ?



BBC narrow : Run12 pp 200GeV

www.phenix.bnl.gov/WWW/run/daq/runcontrol/RunSummary.php?RunNumber=363089													
Indico		Run		PHENIX		goo 辞書		Yahoo! JAPAN					
中川 格		MuID BLT Instructions		www.phenix.bnl.go...		Garmin Connect (6...		A study of the gen...		PHENIX Online Mo...		Run Summary	
	(Begin)	(End)		(Begin)	(End)	(Begin)	(End)	(Begin)	(End)				
CMI	ON	ON	NORMAL	2442	2442	2448	2448	145.4	146.0				
CMO	ON	ON	NORMAL	1720	1720	1696	1697	345.0	347.0				
MMN	ON	ON	NORMAL	2940	2940	2929	2929	76.0	76.0				
MMS	ON	ON	NORMAL	2300	2300	2301	2301	159.1	159.0				

Trigger

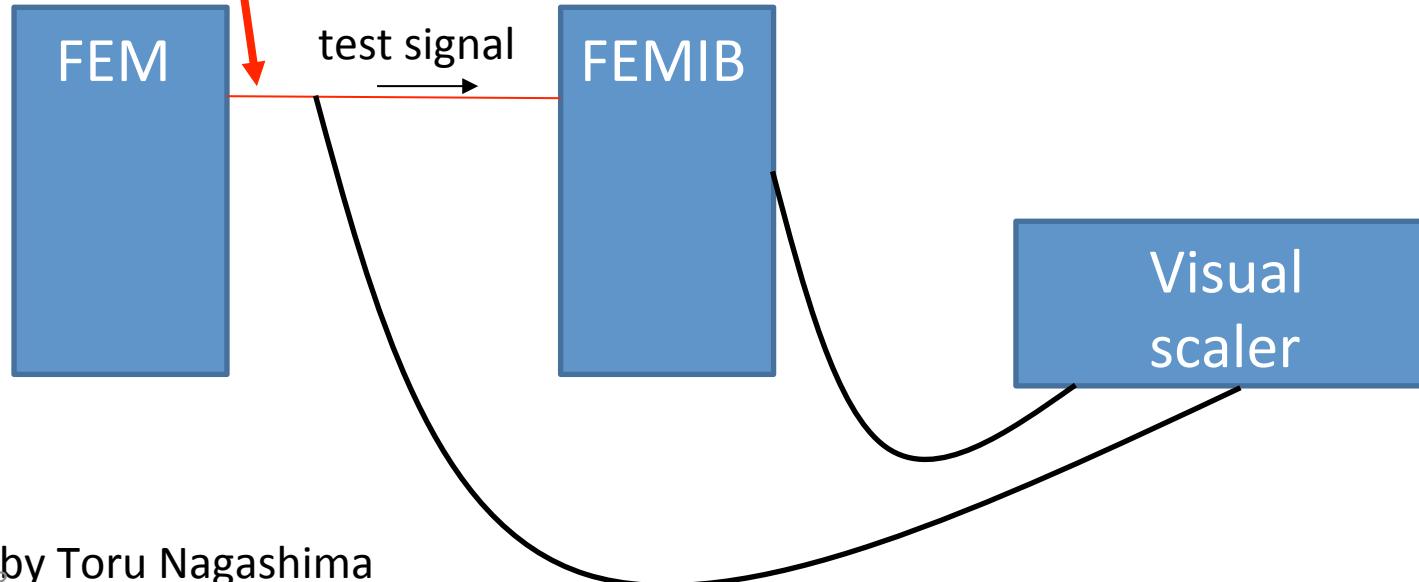
Note: L1 Trigger Scaler Entries in pink indicate an approximate count due to the fact that Run Control may have crashed and the run was not ended properly.
select * from trigger where runnumber = 363089 order by bitnb

Name	Bit Mask	Scale Down	State	Raw Trigger Count	Raw Trigger Rate	Live Trigger Count	Live Trigger Rate	Scaled Trigger Count	Scaled Trigger Rate	Livetime
BBCLL1(>0 tubes)	0x00000001	3299	Enabled	544849709	319935.24	514447999	302083.38	155893	91.54	0.94
BBCLL1(>0 tubes) novertex	0x00000002	1197	Enabled	1057009012	620674.70	998094429	586080.11	833134	489.22	0.94
ZDCLL1wide	0x00000004	58	Enabled	12492867	7335.80	11798396	6928.01	199972	117.42	0.94
BBCLL1(noVtx)&(ZDCN ZDCS)	0x00000008	270	Enabled	107678108	63228.48	101702478	59719.60	375286	220.37	0.94
BBCLL1(>0 tubes) narrowvtx	0x00000010	745	Enabled	253376269	148782.31	239231593	140476.57	320686	188.31	0.94
ZDCNS	0x00000020	58	Enabled	15651509	9190.55	14783232	8680.70	250563	147.13	0.94
ERT_4x4b	0x00000040	0	Enabled	173242	101.73	155075	91.06	155075	91.06	0.90
ERT_4x4a&BBCLL1	0x00000080	0	Enabled	502546	295.09	473511	278.05	473511	278.05	0.94
ERT_4x4c&BBCLL1(narrow)	0x00000100	0	Enabled	1240577	728.47	1170236	687.16	1170236	687.16	0.94
ERTLL1_E	0x00000200	4	Enabled	4635307	2721.85	4328107	2541.46	865621	508.29	0.93
ERTLL1_E&BBCLL1(narrow)	0x00000400	0	Enabled	1102676	647.49	1040449	610.95	1040449	610.95	0.94
CLOCK	0x00000800	19959	Enabled	15974853863	9380419.18	15130127628	8884396.73	758022	445.11	0.95
MPC_B	0x00001000	0	Enabled	925453	543.43	865456	508.19	865456	508.19	0.94
MPC_A	0x00002000	0	Enabled	1512638	888.22	1401509	822.96	1401509	822.96	0.93
MPCN_C&ERT_2x2	0x00004000	0	Enabled	440061	258.40	414191	243.21	414191	243.21	0.94
(MPCN_C & MPCS_C)	0x00008000	0	Enabled	25719	15.10	24127	14.17	24127	14.17	0.94

Signal transmission test



of FEMIB trigger/# of FEM trigger =100%?

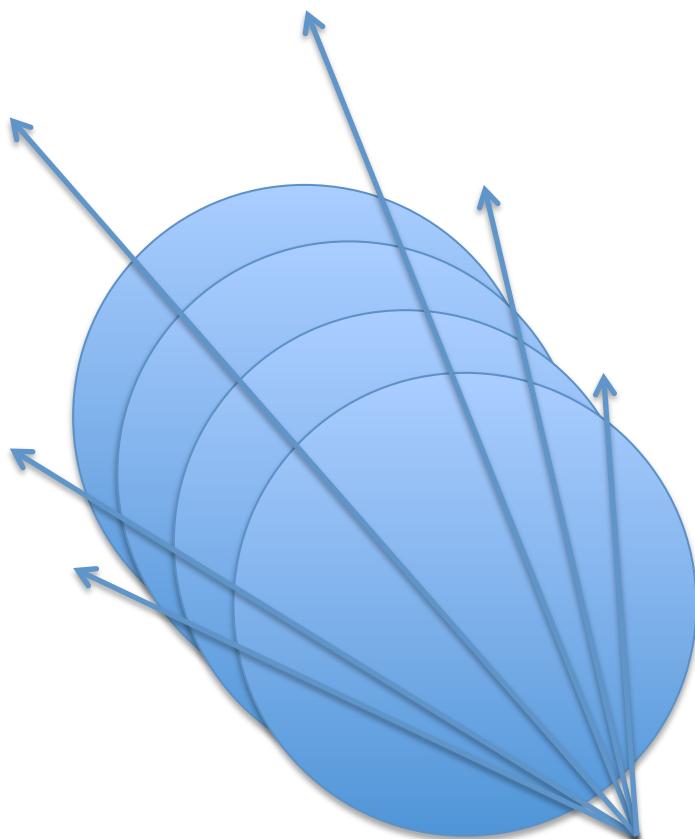


Signal transmission test

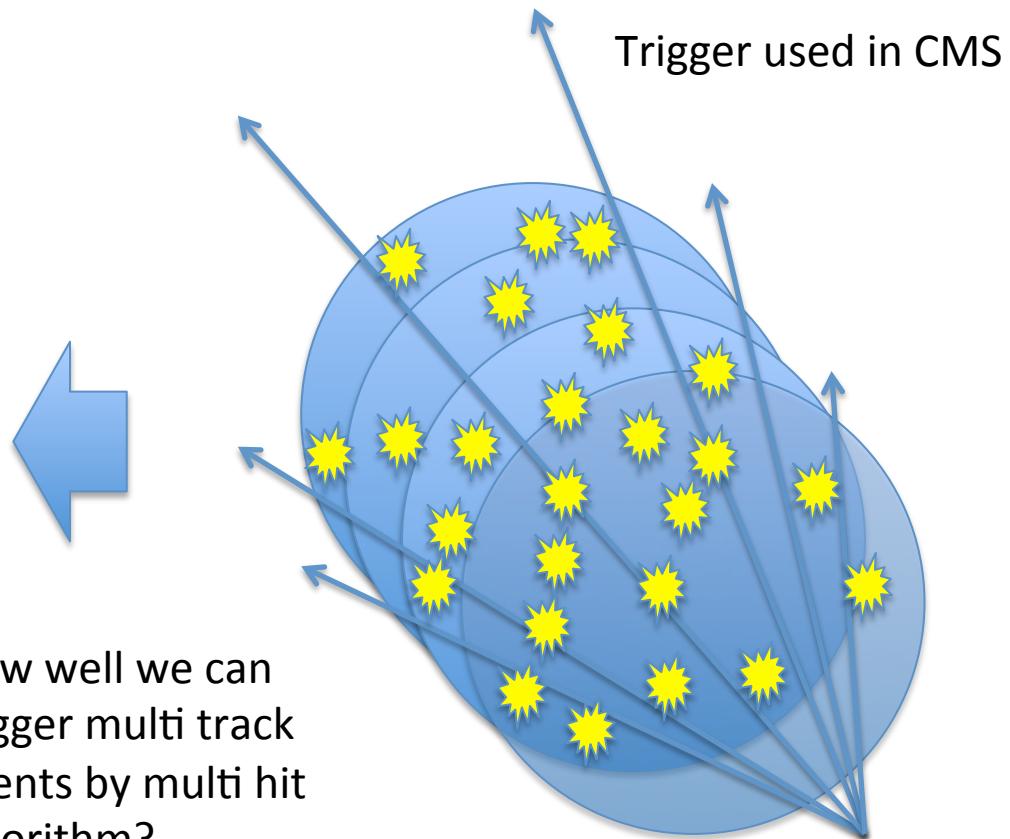
Signal rate	#trigger / #signal
3kHz	100%
300kHz	100%
4.7MHz (BCO/2)	100%

Still need to be tested under some particular condition (continuous FEM trigger through multiple BCO etc.)

Trigger Concept



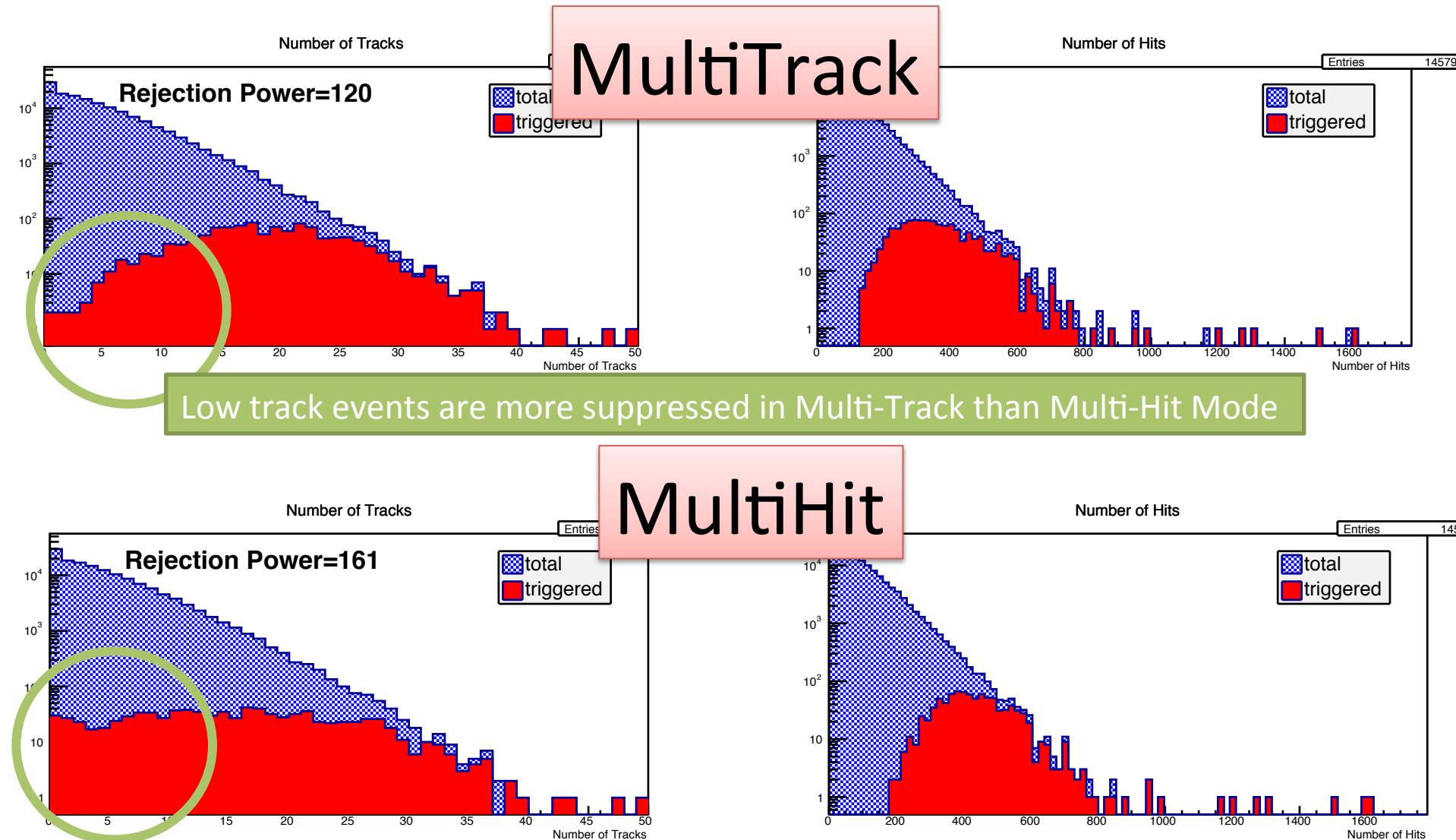
Multi Track



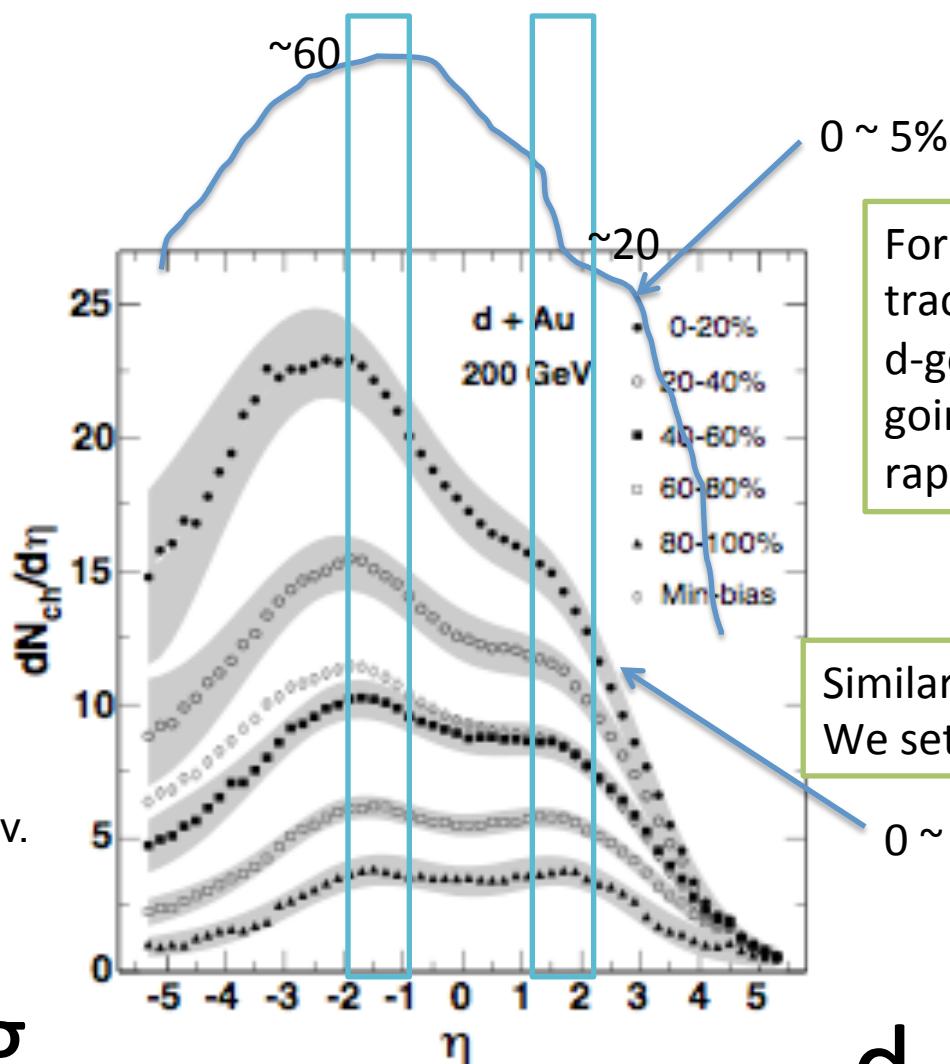
Multi Hit

How well we can trigger multi track events by multi hit algorithm?

Multi-Track vs. Multi-Hit Algorithm



Track Multiplicity vs. rapidity



PHOBOS Phys. Rev.
C72, 031901

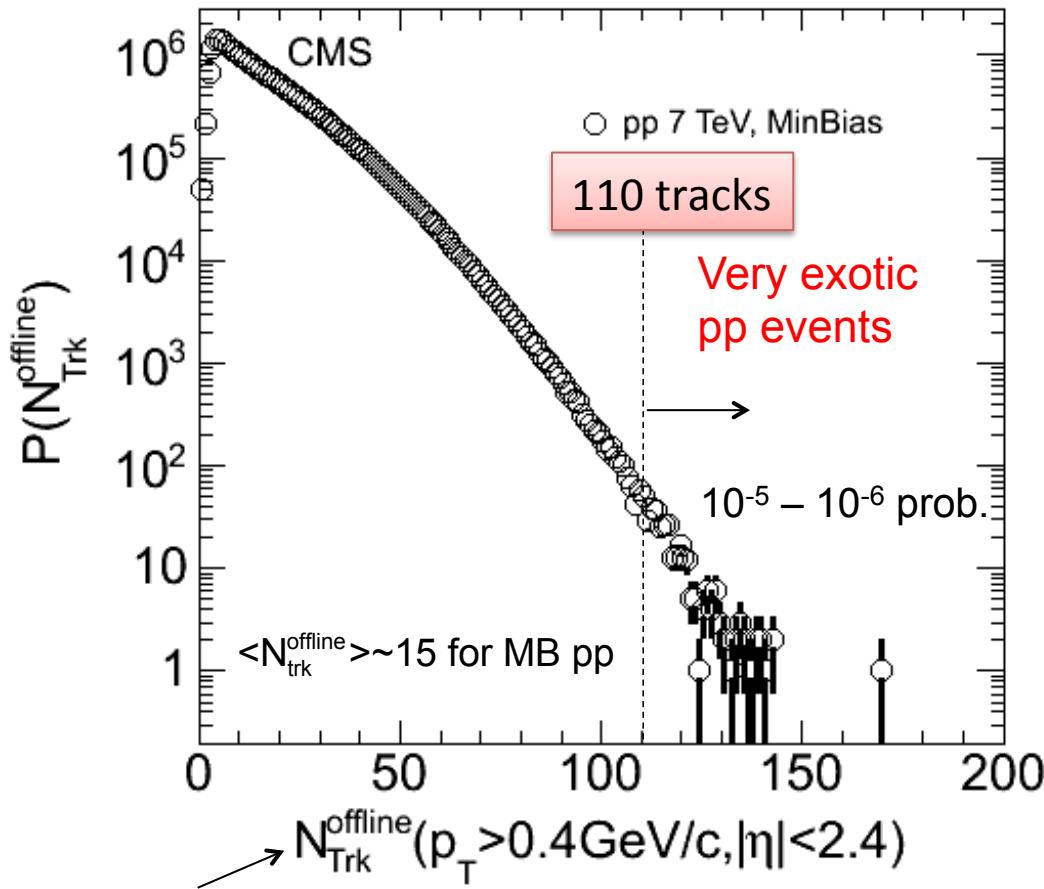
Au-going

Larger

d-going
smaller

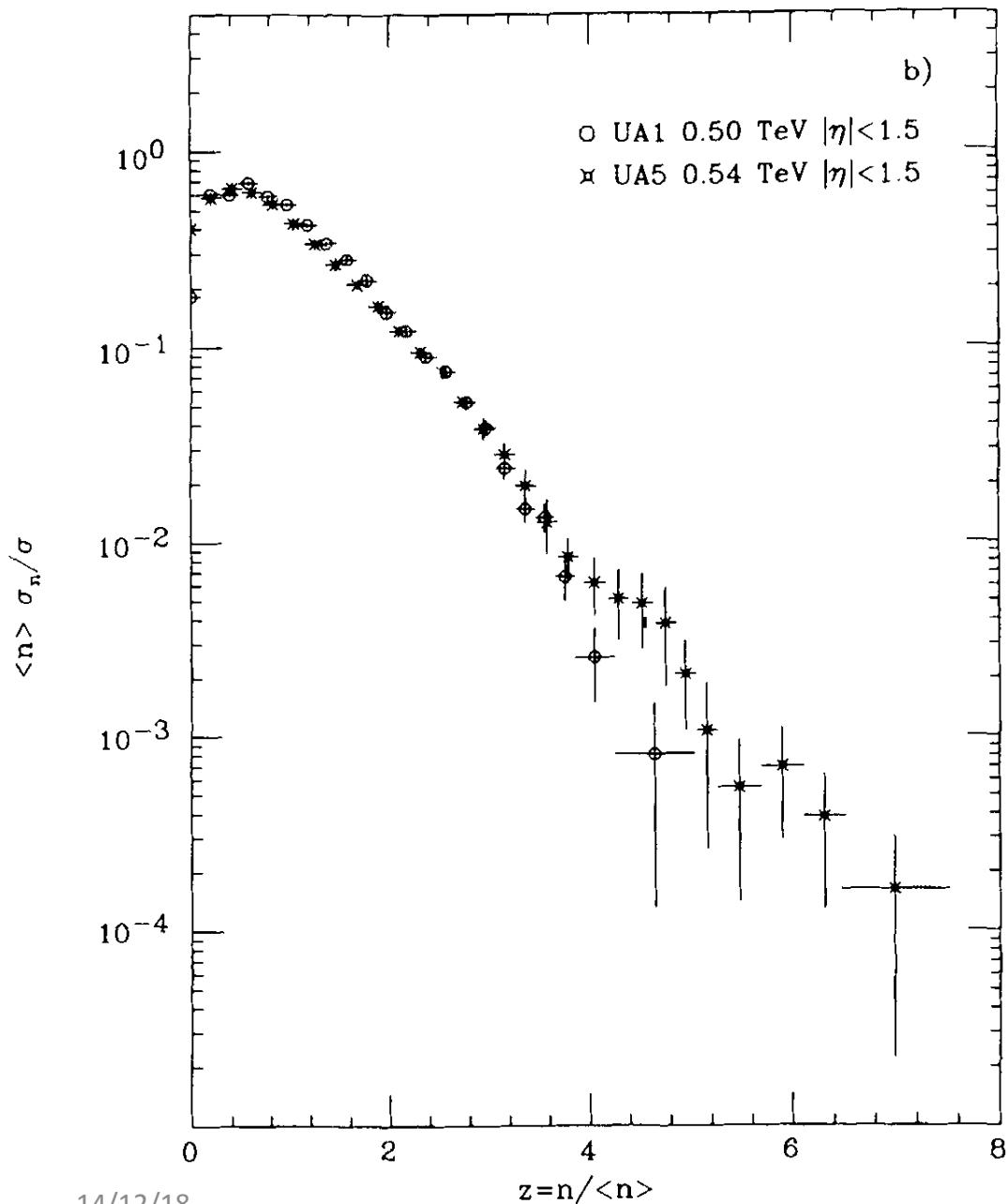
CMS High-Multiplicity Sample

Very high-multiplicity pp events are rare in nature



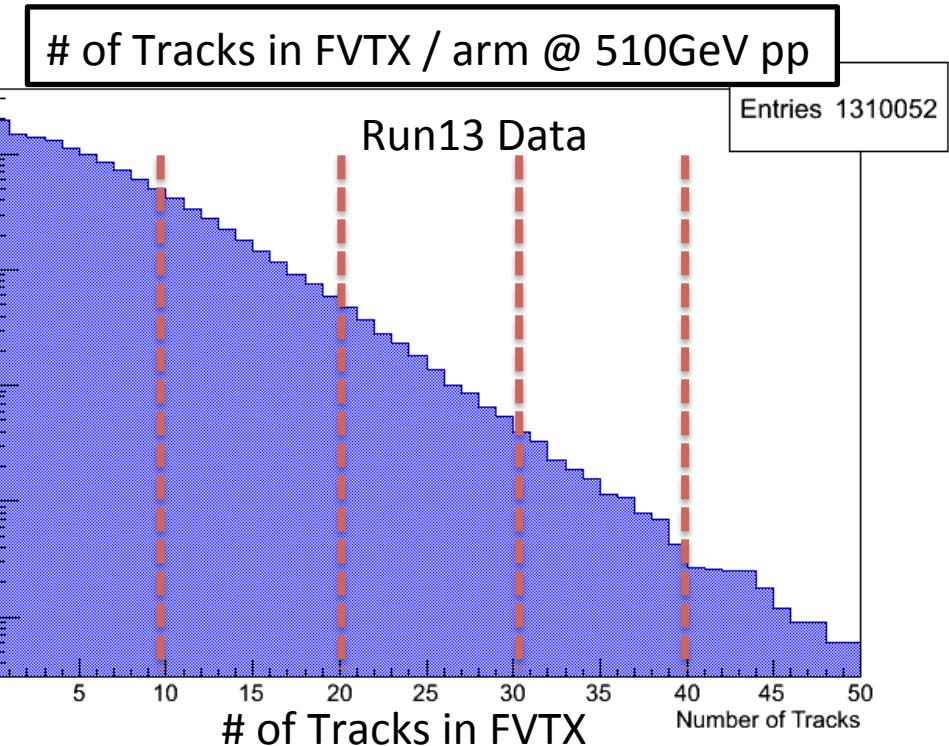
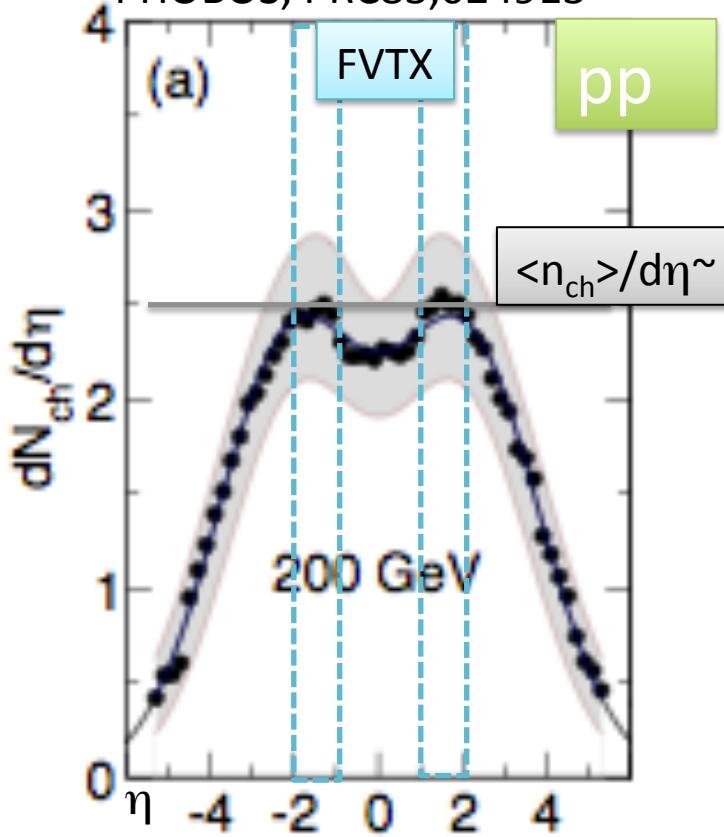
$|\eta| < 2.4$
 $< n_{\text{ch}} > 15$ for MB
 $110 / < n_{\text{ch}} > \sim 7$
 $10^{-5} \sim 10^{-6}$ probability

KNO Scaling



How does this scale to RHIC?

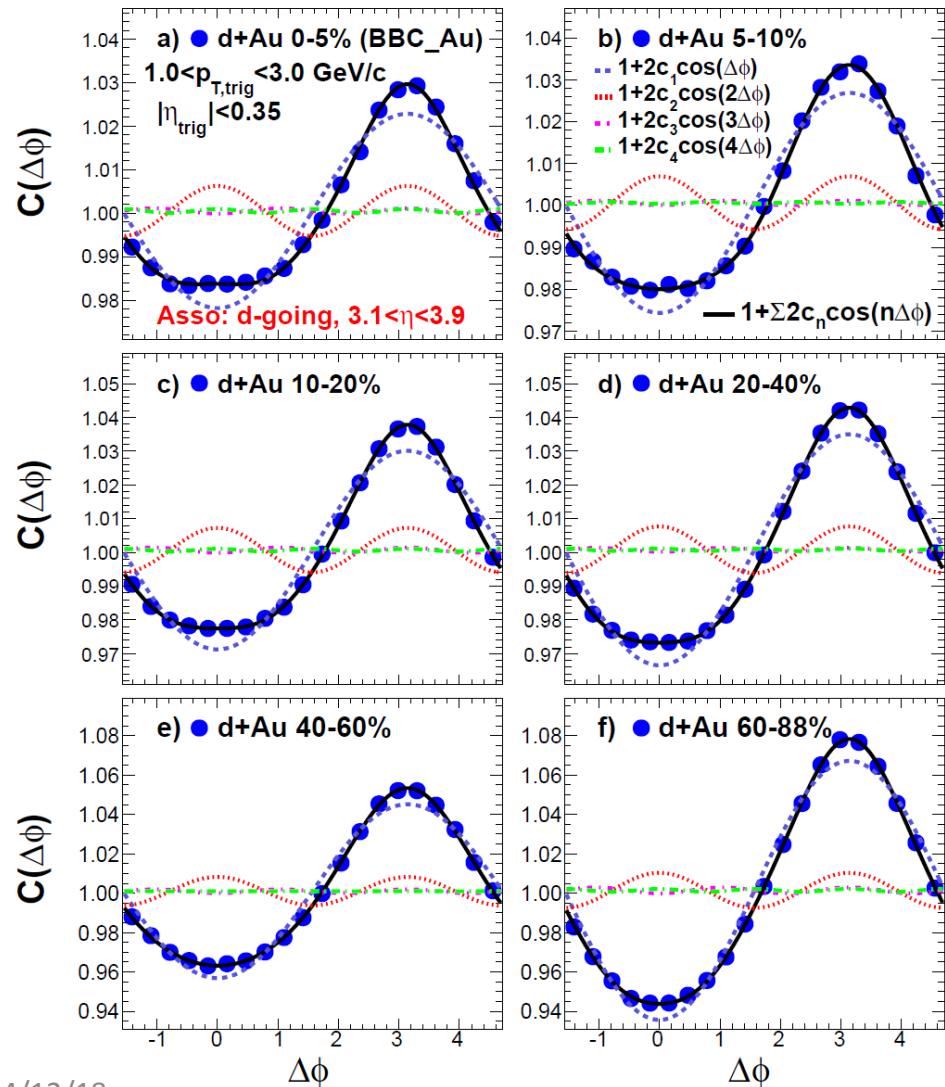
PHOBOS, PRC83,024913



# of Tracks / arm	> 0	> 10	> 20	> 30	> 40
$n_{ch}/\langle n_{ch} \rangle$		4	8	12	16
Fraction in MB	100%	10%	0.7%	0.04%	0.008%
Rates in MB	1MHz	100kHz	7kHz	400Hz	80Hz
Required Rejection Power	1	10	142	2,500	12,500

14/12/18

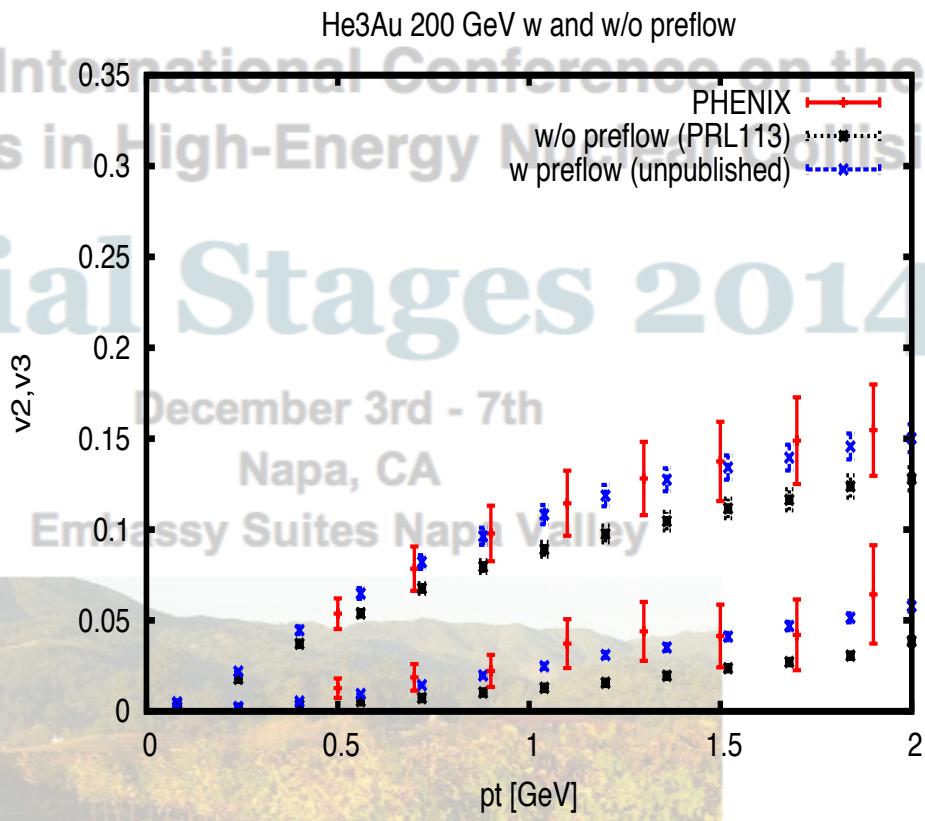
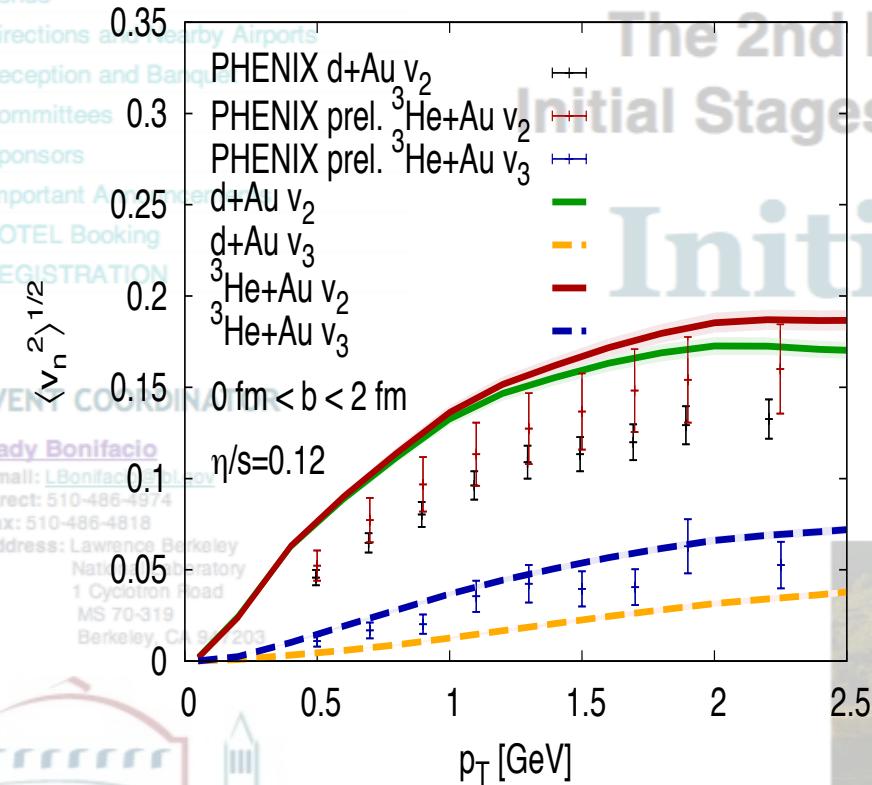
Centrality Dependent v_2



He³Au theory predictions vs data

IP-Glasma+Music

Glauber+hydro+cascade
(Glauber+AdS+hydro+cascade)



Glauber predictions (even w/o preflow) pretty good; don't need IP-Glasma to describe He3-Au

Note

- Trigger efficiency, rejection power and prescale factor do not affect on this total triggered event estimation, because constant 100Hz is assumed.

Goal of Run 15

- FVTX North and South separate trigger bits
- Assuming 100Hz per arm (Total 200Hz)
- $200\text{Hz} \times 3600\text{s} \times 24\text{h} \times 7\text{days} \times 9\text{ weeks} \times 30\%$
DAQ time $\sim 300\text{M}$ high multiplicity events